PENETRATION OF FREE-FALLING OBJECTS INTO DEEP-SEA SEDIMENTS

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THESIS

PENETRATION OF FREE-FALLING OBJECTS
INTO DEEP-SEA SEDIMENTS

by

Jon William Carlmark

Thesis Advisor: R. J. Smith

December 1971

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Penetration of Free-Falling Objects Into Deep-sea Sediments

by

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ABSTRACT

A rational method is presented to predict the penetration of free-falling objects into deep-sea sediments by combining proven empirical theories from the field of soil mechanics with known hydrodynamic phenomena. The impact velocity of the object and the shear strength profile and density of the sediment are assumed to be known. The penetration problem was solved through the use of a computer by equating the work done during penetration to the energy of the object falling through air and impacting onto a modeled deep-sea sediment. The objects were simple geometric shapes ranging in weight from 500 to more than 1,000 pounds. The impact velocities ranged from zero to twenty feet-per-second. The results are compared with full scale tests and recommendations are made to extend the method to a water-sediment interface. The method successfully predicts the penetration of objects into weak, saturated, sediments within the accuracy of the state-of-the-art techniques for measuring the sediment mechanical properties. The impact duration time was observed to be relatively constant and independent of object velocity, shape, and weight implying that it may be a unique property of the dynamic behavior of a sediment type.

TABLE OF CONTENTS

I. INTRODUCTION 8

A. PURPOSE OF INVESTIGATION 8

B. SCOPE OF INVESTIGATION 9

C. HISTORICAL BACKGROUND 11

1. State of Knowledge 11

2. Prior Investigations 14

D. TECHNICAL BACKGROUND 14

1. The Variables Involved 15

2. The Development of Previous Penetration Equations 17

3. Known Variables for Which Data Exists . . 23

II. METHOD OF ANALYSIS 32

A. ASSUMPTIONS THAT PERTAIN TO THE SEDIMENT . . . 32

B. METHOD OF SOLUTION FOR THE AIR TO SEDIMENT CASE 35

1. Role of Hydrodynamics 36

2. Ultimate Bearing Capacity Equations . . . 38

3. The Character of Failure 40

4. The Equation of Motion 41

5. Added Mass Effects 44

6. Transformation of the Equation to Work-Energy 46

7. Method of Solution Used with a Computer . . 48

C. MODIFICATION OF METHOD FOR USE AT SEA 58

III. RESULTS OF EXPERIMENTS 61

A. THE PROBLEM OF MODELING SEDIMENTS 61

B. DATA AVAILABLE 63

1. Description of Objects and Tests 63

2. Description of the Sediment 68

C. RESULTS 85

IV. CONCLUSIONS AND RECOMMENDATIONS 97

APPENDIX A - Forces on Objects Penetrating a Typical Sediment 99

APPENDIX B - Shear Strength Profiles of the Test Pit . . 130

APPENDIX C - Computation of Sphere Penetration 161

APPENDIX D - Computation of a Cylinder Penetrating Horizontally 178

APPENDIX E - Computation of a Cylinder Penetrating End-On 192

APPENDIX F - Computation of the Penetration of a Cube . . 213

APPENDIX G - Computation of the Penetration of a Rectangular Parallelepiped 226

APPENDIX H - Computation of the Penetration of a Cone . . 239

BIBLIOGRAPHY 259

INITIAL DISTRIBUTION LIST 264

FORM DD 1473 266

LIST OF ILLUSTRATIONS

Figure		Page
1	Kelvin and Maxwell Viscoelastic Models	22
2	Forces Acting on a Penetrating Object	42
3	Definitions	49
4	Determining the Depth of "c" for Non-flat Objects	53
5	Outline of Computer Program	57
6	Sphere	64
7	Horizontal Cylinder	64
8	Cylinder-on-end	65
9	Cube	65
10	Rectangular Parallelepiped	66
11	Cone	66
12	Test Pit Mean Shear Strengths	74
13	Location of Drop Stations in the Test Pit	76
14	Shear Strengths at Six-inch Depths Plotted on a Plan View of the Test Pit	78

LIST OF TABLES

Table		Page
I	Constants and Shapes Used for Computations	55
II	Formulas for Calculating Added Mass	56
III	Mechanical Properties of the Sediment in the Test Pit	69
IV	Mineralogical Analysis of the Test Pit Sediment	70
V	Chemical Analysis of the Test Pit Sediment	71
VI	Range of Variation of the Test Pit Sediment	72
VII	Sediment Vane Shear Strengths in the Test Pit	81
VIII	Mean Shear Strengths and Standard Deviations of the Test Pit	84
IX	Summary of Results	86
X	Notes from Penetration Tests	90

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I. INTRODUCTION

A. PURPOSE OF INVESTIGATION

Various types of objects will be lost which fall through the water column and impact on the ocean bottom as man continues to move more freely on the surface and through the oceans. Such objects can range from small and very expensive instrument packages to fleet submarines. It is important to know exactly how far they have penetrated into the bottom during search operations since complete penetration below the surface of the sediments may require a search by other than visual or acoustic methods.

The velocity and free fall attitude of an object that has been located and photographed on the bottom may be estimated from the penetration distance if the physical and mechanical properties of the sediment are known. The impact velocity and attitude could be potentially useful in reconstructing the event and also for determining the amount of energy transferred to the sediment and radiated from the point of impact.

The recovery method and force necessary to break a lost object free of the bottom during a salvage operation will depend to some degree upon how far the object has penetrated into the bottom sediments.

The fields of soil mechanics and foundation engineering have been concerned mainly with static situations including the prediction of the very slow settlement that a structure undergoes as it is erected. The weight is thus applied to

the soil in progressively greater amounts. Deep ocean bottom installations may be preassembled, floated to their site, and allowed to free-fall to a position on the bottom. The free-fall method of implantment is potentially useful for ocean structures since it decouples the structure from the influence of surface motion and tethering lines. Prediction of an accurate initial penetration depth upon contact, therefore, becomes a critical design factor.

An indication of the sediment's mechanical and physical properties can be obtained by observing probes of known physical configuration as they penetrate the bottom since penetration depth depends on sediment strength.

B. SCOPE OF INVESTIGATION

The purpose of this investigation was to develop a method to predict the penetration depth of objects dropped into a simulated deep-sea sediment. Experimental data was available to test and verify the analytical method that was developed. The full scale experiment employed large, heavy objects and it was necessary to let the objects fall through air to allow them to reach a velocity at impact equal to the highest expected terminal velocity of free-fall through sea water for very dense objects. In addition, dropping the objects in air eliminated free fall stability problems as the impact attitude was effectively controlled and the effects of angular momentum on the impact were minimized. The sediment used in the experiment was of re-worked continental origin characterized by low shear strength and high water content typical of deep-sea and pelagic deposits.

The initial boundaries and limitations that were imposed on the study were designed to simplify the complexities of the problem to permit the mechanics to be understood, and to retain the ultimate objective of practical application of the method at sea. The conditions are summarized below.

1. The impact velocity at the top of the sediment column was in the range from zero to 20 feet-per-second. Zero velocity at the top of the sediment column involved releasing the object at the sediment surface and its acceleration through the soft upper layers before coming to rest. The upper limit of 20 feet per second was believed to be a realistic terminal velocity in sea water for most objects.

2. Free fall was assumed, or gravity was the only downward force acting on the object.

3. The object shapes were limited to simple geometries with established hydrodynamic properties from theoretical calculations or empirical tests. Configurations designed to penetrate, such as a coring tool with a long barrel and large mass on one end were not considered.

4. The sediments were taken to be cohesive, with no angle of internal friction. They were also assumed to be low strength, less than four pounds per square inch, and to have high water contents typical of marine sediments.

5. The study did not include the effects of any settlement after initial penetration.

6. The minimum factors necessary to predict penetration depth were considered to be: the impact velocity; geometry and mass of the object; and the shear strength profile and density of the sediment.

C. HISTORICAL BACKGROUND

The loss of the U.S.S. THRESHER and the problems involved in the location of the hull which had penetrated deeply into very soft sediments served to emphasize the fact that little was known about physical phenomena associated with deep-sea sediments and the mechanism of penetration. This disaster prompted the original full scale experiments carried out by the Naval Civil Engineering Laboratory and used to verify the method developed in this study. The THRESHER disaster also pointed out the difficulties involved in sampling sediments at deep ocean water depths and using only a few samples tested in a laboratory to predict as precisely as possible the sediment's dynamic behavior in-situ. This study is only a step toward understanding all the variables and their relationship to each other.

The following is a review of the state-of-knowledge before the investigation and the technical background. The variables involved and the development of other penetration equations are discussed.

1. State-of-Knowledge

The problem of earth penetration by projectiles is a classical one of terminal ballistics and an immense amount of both theoretical and experimental literature exists on the subject. Empirical attempts to determine the thickness of earth embankments needed to protect soldiers were made as early as 1742 [Young, 1969]. In recent years the free-fall penetration problem has been studied to provide protection

against artillery, to estimate forces acting on a structure during earth impact such as would be required by orbiting nuclear power plants that would have to remain intact during re-entry and landing on earth, and to determine physical soil properties remotely by an acceleration-time record transmitted from a projectile penetrometer. The studies have involved the fields of engineering, mechanics, fluid mechanics, geology, soil mechanics, aerodynamics, wave propagation, as well as other disciplines. They were concerned with the problem of a body falling with high velocity through air and impacting on hard continental soils. Bibliographies of prior investigations are available [Schmid, 1969 and Young, 1969]. Dynamic studies in the field of soil mechanics on land are still in their infancy. Whether they can be extended to structures and the penetration problems in the deep oceans probably will remain a question for some time into the future for four basic reasons.

First, the velocity of an object free-falling through water will be much less than the velocity of a similar object in air. At very low velocities, from zero to 10 feet per second, the inertia of the object may not be important compared to other factors. In water the added mass of entrained fluid must be accounted for, but probably would be ignored in air.

Second, continental soils are quite different from deep-sea sediments. Sediments in the ocean basins typically have very small grain sizes, often clay sizes of .005 mm and

smaller. The rate of sedimentation is measured fractions of millimeters per year with very old layered material found relatively close to the top of the sediment column. Deep-sea sediments are completely saturated with interstititial pore water often accounting for half their bulk volume. The pore water is not the pure water commonly found on land, but the chemically complicated sea water which causes flocculation of some sediment particles and the presence of authigenic minerals near the sea-sediment interface. Lower in the sediment column, diagensis and cementation between particles occur forming a loose fabric often with the porosity being relatively constant with depth. The effects of the low 2 degree centigrade temperature and high 6,000 pounds-per-square-inch pressure encountered at the median ocean depth create an entirely different environment than found on the continents. The degree of reworking by benthic organisms may also be important in determining the mechanical characteristics of the upper layers of the sediments.

Third, when measuring the mechanical properties of the sediments, the amount of disturbance that the sample undergoes as a result of the sampling process, handling and preparation for testing, temperature and pressure changes, and organic growth or decomposition is difficult to precisely estimate and may vary from one sampling and testing technique to another [Richards, 1961].

Fourth, if the sediments in the upper layers are treated as a suspension of particles in a fluid, which may

be a valid approach to sediment dynamics if the water content is over 100 percent, then another problem arises. The fluid dynamics of non-newtonian materials have been researched for conduit flows such as slurries in pipelines, but very few investigations of external flow about a body [Pazwash and Robertson, 1969], and unsteady flow at a boundary have been made.

2. Prior Investigations

There are only a few records of objects that have been lost and recovered. The instances where things have been recovered or photographed to document and determine the penetration depth together with adequate data about the mechanical properties of the sediment are virtually nonexistent. The same lack of data exists in reports written about the few cases where penetration was investigated. The reports typically set forth equations with empirical constants and contain no information about the controlling sediment parameters.

Much literature and empirical information is available about pile driving. The forcing of a long piling into soft sediments is, however, quite different from the free-fall penetration problem.

D. TECHNICAL BACKGROUND

All of the variables were studied, then the development of the previous penetration equations was researched before an attempt was made to solve the penetration problem. A review of the known variables for which data exists was made

to develop a method that would be of use at the present time using available data and techniques.

1. The Variables Involved

Penetration may be a function of more than 20 different variables and may be described by the following equation:

$$f\,(V_o, M, A, z, e, r, S, E, \nu, \rho_s, T, \phi, w, s, \xi, \mu_w, \mu_s, c, k, \gamma, \delta, \rho_w, a_s, h) = o \qquad (1)$$

where,

V_o = impact velocity

M = mass of the object

A = cross sectional area of the object

z = depth of penetration

r = surface roughness of the object

S = object shape

e = void ratio of the sediment

E = Young's modulus of the sediment

ν = Poisson's ratio of the sediment

ρ_s = density of the sediment

T = time for penetration to occur

ϕ = mineralogic and chemical composition of the sediment

μ_s = viscosity of the sediment

c = shear strength of the sediment

k = permeability of the sediment

s = sensitivity of the sediment

w = water content of the sediment

γ = dilation of the sediment

δ = grain size of the sediment

ξ = post depositional changes of the sediment

ρ_w = density of the water

μ_w = viscosity of the water

h = water depth

a_s = adhesion of the sediment to the object

Such a list is self explanatory and is not exclusive. Some of the above properties are related to others, and the parameters may thus be reduced in number by a dimensional analysis [Liu, 1969]. Some of the properties, however, are not amenable to a mathematical analysis, for example the grain size distribution and the grain's morphology and orientation in the sediment fabric. A phenomological approach to the problem may, therefore, be required [Muga, 1966]. To put all of the variables into a system of equations may be an impossible task, and for this reason the prediction of penetration into deep-sea sediments may remain somewhat of an art and not susceptible to an exact solution for some years.

The deep-sea sediment particles accumulated over millions of years occur in many types which reflect unique depositional conditions of the earth's history. The mechanical properties vary widely, as subsequent to deposition the sediments may have undergone secondary cementation, diagenesis, recrystallization, and a degree of reworking by animals in the top important layers [Smith, 1969]. Some problems involved in learning more about deep-sea sediments are set forth in the following paragraphs.

The details of the sea-sediment interface and upper sediment layers in the depths of the ocean are only grossly known the world over. In the most studied ocean, the North Atlantic, Keller [1967], estimates one core has been analyzed for sediment mechanical properties for every 30,000 square miles of ocean floor. Less data is available in the Pacific. The variation of the ocean bottom's nature and the high cost of about 1,000 dollars per foot of core recovery and analysis will limit any great expansion of knowledge.

Much input to the design of foundations on land is based on past local experience incorporated into local building codes. On land, tests can be conducted and equations developed that fit special circumstances in certain areas at considerably less expense than in the oceans. Also a past history exists for land areas of interest, whereas comparatively little has been known of deep-sea sediments until very recent times. Although the horizontal area variability of deep-sea sediments may be less than that of continental sediments, to empirically categorize the seventy percent of the earth's surface covered by water and anticipate a return in less than the number of years that have elapsed since structures have been built on land would be folly.

2. The Development of Previous Penetration Equations

A review of the development of penetration equations emphasizes the importance of the various constants that act to control the penetration depth. The discussion that follows combines the outlines given by Schmid [1969], and

Young [1969]. First and most basic from Newton's second law,

$$F(t) = M\ddot{x}(t) \tag{2}$$

it can be shown that penetration depth is determined if velocity is known as a function of time. In general this is not the case for unsteady motion at a boundary.

Other classical equations are also based on Newton's second law where resistance to penetration is a function of the instantaneous velocity, V;

$$-M\ddot{x} = C_1 + f_1\ (V) + f_2\ (V^2) + \ldots f_n\ (V^n) \tag{3}$$

which postulates that during the first phase of penetration, at high velocity, the motion is governed by resistive forces proportional to velocity to some power, and at the final stages of penetration the resistance is independent of velocity. If the functions, f_1, f_2, $\cdots$ f_n, are taken to be constants and the highest power of n assumed to be 2, then equation (3) simplifies to;

$$-M\ddot{x} = \alpha + \beta V + \gamma V^2 \tag{4}$$

where at high velocities the forces controlling penetration are proportional to V^2 or analogous to drag force in fluid flow. At moderate velocities resistance will be proportional to the first power of V, analogous to viscous resistance, and at the last stage, proportional to a constant force independent of velocity. According to how the constants in equation (4) are treated, the following classical equations can be derived after integrating twice with the initial conditions,

$V = V_o$ at $t = o$, and final conditions, $V = o$ at $t = T$.

Robins-Euler $$z = \frac{M\, V_o^2}{2\, \alpha} \quad \text{(constant resisting force)} \tag{5}$$

Poncelet $$z = \frac{M}{2\gamma} \ln \left(1 + \frac{\gamma V_o^2}{\alpha}\right) \quad \text{(resisting forces constant and similar to fluid drag)} \tag{6}$$

Resal $$z = \frac{M}{\gamma} \ln \left(1 + \frac{\gamma V_o}{\alpha}\right)^2 \quad \text{(resisting forces similar to fluid viscosity and fluid drag)} \tag{7}$$

The question relative to the use of the above equations rests with the constants, α, β, γ, which are determined by the geometry and mass of the object and the type of medium being penetrated. Schmid [1969] discussed several empirical penetration equations from the literature which are variations of the above classical equations. The constants were determined from high velocity impacts on continental soils.

Thomason and others [1968] used Poncelet's equation to determine the amount of charge required for an explosive anchor system.

$$z = \frac{P}{2\, gib} \ln \left(1 + \frac{b}{a} V_o^2\right) \tag{8}$$

where

$p = \frac{W}{A} = \frac{\text{weight of projectile}}{\text{normal frontal area}}$

a = constant related to the shatter strength of the medium (for "mud" a = 320 psi)

b = an inertial coefficient for the material

i = a form factor, usually 1.0

Evaluation of a and b is a problem and unfortunately a comparison of predicted and actual penetration was not given. However, the penetration depth's dependence on high velocity was illustrated.

Young [1969] presented a semi-empirical solution to the penetration problem derived from 160 full scale tests on continental soils with impact velocities ranging from 100 to 1,000 feet-per-second. Penetration was treated as three phases: (1) impact, (2) moving through the soil, and (3) coming to rest. The phenomena of entry is not the same as moving through the soil, but the surface effect of entry was found to be negligible after the object had penetrated three body diameters. The basic form of Young's equation was:

$$z = f_1\ (S)\ f_2\ (A)\ f_3\ (W)\ f_4\ (V_o)\ f_5\ (N) \qquad (9)$$

where

S = a shape parameter of the object

A = cross sectional area of the object

W = weight of the object

V_o = impact velocity

N = constant dependent on soil properties averaged over penetration distance

Two equations were determined for two ranges of velocity, one for less than 200 feet per second and one for greater than 200 feet per second. The low velocity equation was:

$$z = 0.53\ (N)\ (S)\ (\frac{W}{A}) \ln\ (1 + 2 \times 10^{-5}\ V_o^2) \qquad (10)$$

and nomograms were given for easy solution. All Young's data fitted within ± 20% deviation. Again it should be noted that

the soil property constant, N, could vary by a factor from 1 to 50 and "was arbitrarily assigned by those knowledgeable in the field".

If penetration is treated as being resisted by viscous forces only, the following results according to Schmid [1969];

$$M\ddot{x} = A\,V(t) \tag{11}$$

which has as its solution

$$x = \frac{V_o}{\alpha}\left(1 - e^{-\alpha t}\right) \tag{12}$$

where

$$\alpha = \frac{A\mu}{M} \tag{13}$$

When t goes to infinity, the maximum penetration becomes:

$$z = \frac{V_o}{\alpha} \tag{14}$$

but again resolving the viscous parameter of the sediment, μ, and establishing a realistic time, t, become difficult.

Soils do not behave as isotropic, linearly elastic materials, except possibly at very small strains [D'Appolonia and Lambe, 1970]. Penetration into a material causes the elastic limit of the material to be exceeded and theories of elasticity cannot be applied directly to the problem. Theories of elasticity and plasticity applied to problems of deformation assume idealized stress strain laws which are not well suited to soils and more basically ignore the important dimension of time, and assume that the state of strain is instantaneous.

Various viscoelastic models, Figure 1, with combinations of Kelvin and Maxwell models, of a sediment can be

assembled and solved by Laplace or Fourier transforms, if time dependence is linear.

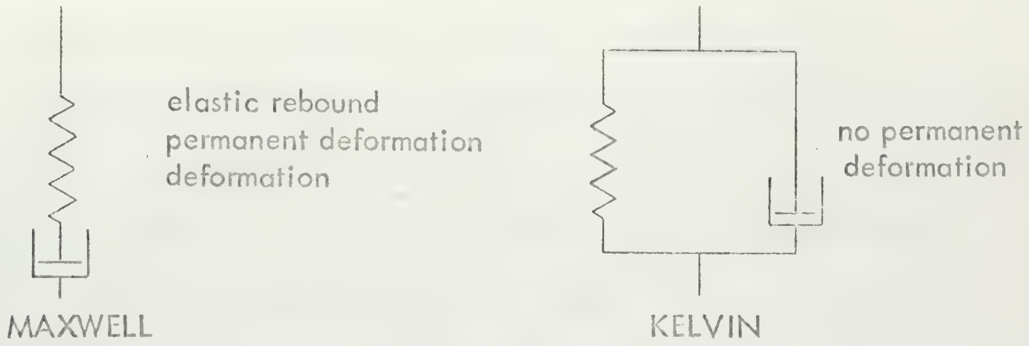

Figure I. KELVIN AND MAXWELL VISCOELASTIC MODELS

However the problem of determining the necessary soil parameters is non-trivial, and to get a unique solution, several sets of parameters are required [Schmid, 1966].

Modern advances in rheology and the continued development of the finite element method with appropriate yield criteria such as developed by Noh and Wilkins in 1964, and outlined by Schmid [1969], and the analysis of the initial settlement problem by D'Appolonia and Lambe, [1970], may be useful but again the problem of relating all parameters and determining the stress-strain behavior and yield criteria of a rheologically complicated material such as deep-sea sediments, may remain elusive for the near future.

In very weak, high water content, deep-ocean sediments, the penetration problem is somewhat similar to the problem of ship slamming. Studies of ship slamming and unsteady hydrodynamic impacts at a water surface have mainly been concerned with peak pressure, velocity-time relationships as a function of the form of a structure as it penetrates

a fluid boundary and not penetration depth. Extensive literature and model test records exist [Ochi, 1962].

A method to estimate the impact velocity from the observed penetration depth was developed by Mandl and Givens [1964] after an aircraft was lost and crashed into soft clays in northern Canada. The method developed and explicity solved an equation of motion for a sphere and cylinder penetrating at high velocities into a Leda clay

$$-(m' + M)\ddot{x} = Mg - F - D \tag{15}$$

where

F = the static strength of the clay, a function of penetration depth only

D = a drag force considered a function of penetration depth, velocity and time

Experimental tests of high velocity impacts into clay, (greater than 800 feet per second) confirmed that the method overpredicted penetration depth. The over-prediction was expected since viscous dissipation and elastic wave initiation were ignored.

After a detailed examination of mathematical methods available for analysis of unsteady motions of an object crossing an air-water interface, Moran [1965], concluded that none of them could yield a uniformly valid approximation to the solution of surface crossing and that the best hope for obtaining a reliable estimate was with numerical analysis.

3. Known Variables for Which Data Exists

Since all of the methods reviewed rely totally on the ability of the selected variables and constants to correctly

parameterize the penetration problem, it was necessary to review what is known about the variables. The physical properties of the object are assumed to be known but the description of the sediment strength is subject to the interpretation of empirical tests or, in some instances, phenomenological observations. Even though deep-sea sediments are very different from continental soils, a review of what has been learned about the mechanical behavior of fine-grained clays on land and what is known about deep-sea sediments is necessary to assemble a workable solution. Also the problems of sampling and testing at sea cannot be ignored.

Information about the following parameters; density, water content, void ratio, shear strength, and sensitivity, which describe the mechanical behavior of deep-sea sediments, either exist in the literature or may be easily determined through laboratory tests which have been standarized and soon may be routinely performed at sea on oceanographic vessels.

The bulk density of deep-sea sediments is determined from routine measurement of the weight of a known volume of sediment. Typical values range from 74 to 125 pounds per cubic foot with the most common sediments in the range from 78 to 109 pounds per cubic foot [Keller, 1967]. The bulk densities of North Pacific sediments are generally lower than those of the North Atlantic.

The void ratio and porosity are a measure of the volume of sediment in a sample compared to the volume of

voids, which are filled with sea water in the case of deep-sea sediments. They are also a measure of particle point to point contacts and bonds [Schmid, 1969]. The measurement is easily made with a pycnometer that measures that volume of a known weight of oven-dried sediment.

Sensitivity, the ratio of the original undisturbed shear strength to a remolded and disturbed shear strength, is important to the penetration problem since the object moves through disturbed sediment during penetration. Its importance is hard to estimate since most samples are disturbed to some degree. Mitchell and Houston [1969] indicate that in the range of sensitivity from 1 to 8, typical of deep-sea sediments, the mechanism that causes sensitivity is chemical cementation, which is not well understood by soil mechanists but obviously important.

For a cohesive sediment, the strength is a measure of the sediment's ability to resist mechanical deformation. Large masses of cohesive soils generally fail along a surface and hence the strength of a cohesive soil is defined as shear strength. For purely cohesive sediments undergoing large deformations, particle to particle interactions which would cause an "angle of internal friction" and increase in the strength of the sediment are generally assumed not to exist. However, as more sophisticated testing techniques are developed, this may prove to be an erroneous assumption.

Typical values of shear strengths were given by Keller [1967] to range from .25 to 2.5 pounds-per-square-inch, with

the most common range between .5 and 1.5 pounds-per-square-inch. The North Atlantic basin sediments have slightly higher strengths than the North Pacific. The presence of carbonates will increase shear strength, but few carbonates are found below 12,000 feet. In the Gulf of Mexico, Bryant and others [1967], found shear strengths of silty clay turbidites of the abyssal plains to range from .3 to 1.1 pounds-per-square-inch with the pelagic sediments of the continental slopes having strengths up to 5.9 pounds-per-square-inch.

Richards [1967] predicted that a reduction of in-situ strength would be caused by sampling and laboratory testing and that the reduction might be proportional to the grain size, the amount of gases in solution, and temperature increases that cause increased bacterial action. However, samples tested in-situ at 300 meters with a vane device correlated well with tests from cores taken from the same area a year earlier and tested with a fall cone and laboratory vane [Richards, 1967]. Recent experience indicates this may have been an isolated instance of agreement.

Laboratory tests to determine the effects of temperature and pressure on shear strength and consolidation have been carried out with greatly disturbed, remolded samples [Vey and Nelson, 1966]. The results were somewhat inconclusive due to the small number of samples and difficulties in instrumentation. The results indicated that there was a decrease in direct shear strength with increased environmental

pressure for a fine grained sediment with high void ratio. The vane shear tests with increased environmental pressure showed an increase in shear strength for plastic sediments and a dec
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be physically contained during
ting. This precludes the use of an unconfined compression test or any test that requires trimming the sample before testing. The vane shear and fall cone tests can be done on a sample in its original container and the vane shear has the added advantage of easy adaptation to in-situ testing. Kravitz [1970] compared the results of Wykham-Farrance vane, Torvane, and fall cone tests on weak sediments and found that the results

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from the fall cone were more repeatable than the Wykham-Farrance vane or the Torvane which showed least repeatability. These results may have been expected since an important factor in vane shear testing is the rate of loading and the separation of static and dynamic resistance [Housel, 1959].

The vane test's advantages are: First, it can be conducted in-situ and a strength-depth profile is easily obtained where all other methods require reentry of a hole, which may be very difficult in the deep ocean, or discrete sampling which disturbs the sediments. Second, it is a simple inexpensive technique when compared to sampling and laboratory testing. Third, it does not require a system of weights or free-falling objects to cause the soil to fail and therefore has the potential to be used at sea on a rolling, pitching ship.

The vane test limitations can be summarized as: First, it can only be used in uniform, saturated, cohesive sediment. Second, when done in-situ it does not obtain a sample for evaluation. Third, it imposes a failure surface which may not be the weakest surface or relevant to the problem being studied.

Eden [1966] found that the vane will yield higher strengths with more consistent results in sensitive clay with shear strengths less than ten pounds per square inch when compared to a fall cone. This is in conflict with the more recent tests of Kravitz and emphasizes the problems in testing. Kravitz made statistically significant tests on a

laboratory prepared montmorillonite sample and Eden tested natural clays.

Shear strength values from a vane were found to be 15% higher than those obtained by an unconfined compression test on Gulf of Mexico slope sediments [Morelock, 1969]. This may be partially balanced by the findings of Inderbitzen [1970] who found that laboratory vane measurements were 22% lower than in-situ measurements made from DEEP QUEST at a depth of 3,500 feet. This is in rough agreement with the estimation made by Crisp [1968], of a decrease in shear strength due to an expansion of pore water caused by temperature and pressure changes. Crisp estimated that an expansion of pore water by two percent would occur by raising a sample from 12,000 feet deep and 2 degree centigrade temperature to surface temperature and pressure. This expansion could significantly alter the strength properties of a sediment and Crisp showed shear strength should decrease 10 to 15 percent.

The in-situ tests conducted by Inderbitzen showed a uniform increase in strength with depth in the sediment, but the laboratory tests were erratic, suggesting that the difference may have been caused by disturbance during sampling and preparation for testing.

Penetrometers offer the great advantage of potentially being self-contained instruments. They either record or transmit a force versus time curve from which depth of penetration by integration and soil properties can be

inferred. In order to extrapolate to different shapes and velocities, however, the curve's shape must be a characteristic of the sediment parameters. There are real problems with instrumentation and directional stabilization as the penetrometer penetrates since centric impact rarely occurs with other than symmetrical objects [Schmid, 1966]. Three other problems also complicate the penetrometer approach to determining sediment properties in the oceans. First, to get deep information, the penetrometer must have enough energy to penetrate, and at low terminal velocities in water it will probably require a smooth, known, driving force. Second, viscous forces may predominate on small penetrometers making extrapolation to larger objects very difficult. Third, penetrometers do not retrieve samples for analysis of other sediment parameters.

Acoustic sounding and seismic methods do not discriminate enough of the structure of the upper layers of sediments important to the penetration problem to allow their use at the present time. In the future the use of high frequency pulsed sources mounted on deep vehicles, hold promise for better resolution of the upper layers.

The methods of determining sediment strength that have been discussed were developed for use in classical foundation engineering where a safety factor based on engineering judgement would be applied to the final result. The penetration problem is quite different as it requires an exact answer since an error factor of two could mean the

difference between an object being completely buried below the surface or having one half of the object exposed and easily located.

II. METHOD OF ANALYSIS

Prior to a discussion of the method used to solve the penetration problem in the air-to-sediment case and the modifications required for use at sea, it is suitable to quote directly from Terzaghi and Peck [1948].

> "Because of the unavoidable undertainties involved in the fundamental assumptions of theories and in the numerical values of the soil constants, simplicity is of much greater importance than accuracy. If a theory is simple, one can readily judge the practical consequence of various conceivable deviations from the assumptions and act accordingly. If a theory is complicated, it serves no practical use until the results are condensed into graphs or tables that permit rapid evaluation of the final equations on the basis of several different assumptions."

A. ASSUMPTIONS THAT PERTAIN TO THE SEDIMENT

Deep-sea sediments are not well defined in the literature dealing with soil mechanics. Therefore a list of important assumptions considered in developing the penetration prediction method are stated:

1. The sediment is completely saturated with sea water.

2. The water content of the sediment is 75 percent or more, as is typical of marine deposits in the deep ocean basins.

3. Organic material that would tend to bind the sediment particles together is either absent or is present in very small quantities.

4. The sediment will fail along its weakest plane.

5. The only shear resistance is cohesion.

6. The initial penetration takes place in such a short time that the effect of permeability is nil. In a study of time-dependent deformation of clays Barden [1969] noted that the effect of adsorbed water on individual particles was that pore pressure equals the applied pressure at the first application of load.

7. Any lithification or cementation that may have developed along individual particle-to-particle contacts is broken at the time of impact. This implies a portion of the sediment is remolded at impact. If the particles do not react with one another by other than mechanical means, the mixture will behave as a viscous fluid [Peck and others, 1953, Pazwash and Robertson, 1969].

8. Shear strength varies in an irregular manner with depth. The variation of velocity gradients is greater in the deep ocean basins than over shallow areas [Ewing and Nafe, 1963] which implies that deep ocean sediments have been deposited in layers. This is confirmed by visual observation of deep-sea core samples which often show horizontal layers of different colors and textures. When studying in-situ strengths, Inderbitzen [1970] found that horizontal variations were much less than vertical variations. He also

found that the percentage of variation in shear strength decreased with depth, which may indicate that biological and chemical processes are taking place in the upper layers and minimal consolidation occurs.

9. The bulk wet density of the sediment can be considered constant with depth in the surficial sediments. The shear strength of a saturated sediment depends to a large extent on the structural arrangement of the particles and Scott [1967] points out that soils can have different structures at the same density, but may not have the same structure at different densities, which implies that shear strength is not a unique function of density. X-ray diffraction and polarized light microscope techniques cannot reveal the details of particle configuration or orientation in fine-grained marine sediments. However, electron microphotographs of sediments from the Gulf of Mexico show them characterized by a loose, open arrangement of randomly oriented particles and that particle rearrangement resulting from gravitational consolidation is not apparent [Bowles, 1969].

10. The energy transmitted to the sediments in the form of elastic or gravity waves from the initial impact shock is negligible in comparison to the total energy dissipated during penetration. Impacts on soils and fluid media have been studied for a long time, but there is a very difficult instrumentation problem with detecting energy transmitted away from the impact site. According to Hunter [in Schmid, 1966] the Hertz impact theory, which refers to impacts in the elastic

range, states that the portion of total energy that is vibrational energy is very small as long as the impact velocity is less than the velocity of sound in the medium. Schmid [1966] measured the distant dynamic disturbances caused by a small penetrometer impacting into materials whose rheological properties were known or easily tested, such as, greases, wax, and homogeneous soils. High frequency vibration was detected in the hard materials and it was determined by use of surface accelerometers that the largest amount of energy propagated from the point of impact was 4.3 percent of the total energy available. His calculated propagation speed suggested that the motions measured at the surface were Stoneley waves. Ochi and Bledsoe [1962] when conducting model tests of ship hull forms slamming onto a water surface found that forces were very large for .01 seconds and pressure due to impact phenomena were over within .07 seconds, yet the model's velocity decrease during this time was less than 4 percent. Chuang [1970] in a similar investigation, did not detect any significant acoustic pressure variations at a distance away from the impact point and concluded that water could be considered incompressible for impact velocities from 0 to 50 feet per second.

B. METHOD OF SOLUTION FOR THE AIR-TO-MUD CASE

A rational, phenomenological approach was used to solve the penetration problem rather than an empirical method because of the poor state of knowledge that exists relative to actual behavior of deep-sea sediments. With engineering

judgment, this method may be extended to different objects and different cases more easily than an empirical approach to the problem.

1. Role of Hydrodynamics

The sediment was treated as a homogeneous, incompressible fluid to enable an estimate to be made of (1) the momentum transferred from the body to the sediment, and (2) the drag forces exerted on the object at high velocities. If the sediment was a true fluid it would have an infinite strain for an applied stress. Therefore, the forces required to initiate failure in the sediment and bring the body to rest were taken as the forces calculated using the ultimate bearing capacity formula developed by Prandtl and Terzaghi.

Treating deep-sea sediments as fluids has been an approach applied to the study of turbidity flows and slumping on the continental slopes. The term "spontaneous liquefaction" is often used when referring to saturated clays and implies fluid properties. Briefly, Morgenstern [1967] states that liquefaction occurs when the sediment is loaded to the collapse stress of the sediment fabric and the load is then transferred to the interstitial pore water. The increase in pore pressure then produces hydraulic gradients which further disrupt the sediment fabric causing the solids and pore water to flow macroscopically as a viscous fluid. Houston and Mitchell [1969] describe the fluid phenomena as occurring in sensitive clays which contract during shear because of their open fabric. If the clays are saturated, the contraction tendency

results in a large transfer of normal stress from the clay skeleton to the pore water causing pore pressure to increase. In saturated deep-sea sediments this transfer of normal stress may be almost instantaneous. Continuing the description of Houston and Mitchell [1969], as the remoulding caused by continuing strain becomes more pronounced, the effective normal stress may fall to a very low value. Very little strain is required to break bonds at particle contacts and there is some build-up of pore pressure even before a significant number of bonds are broken because of slight elastic compression of the fabric and incompressibility of the pore water. The resistance of sensitive clays due to dilational energy was determined to be small or absent by Houston and Mitchell [1969], and Walker [1969]. Because, first, at high void ratios little or no tendency toward dilation was observed during shear, even at high strains, and second, the effective stress had been so reduced at high strains the mobilized resistance of the clay fabric was small. Mandl and Givens [1964] when conducting high velocity penetration tests into a clay, judged that the compressibility phase of impact lasted until the surface boundary breaks and that the static yield strength of the clay was exceeded by many orders of magnitude under impact and the clays behaved in a dynamic manner similar to a fluid. Schmid [1966] when conducting low velocity free-fall impact experiments on a clay also observed that liquefaction occurred.

Another reason to treat deep-sea sediments as a fluid was that their bulk wet density has a narrow range of variation

with depth in the upper layers of sediment and the assumption of a median density over the range of expected penetration is a good approximation.

2. Ultimate Bearing Capacity Equation

The bearing capacity of a soil is a measure of its ability to support a load relative to its limiting equilibrium. According to Harr [1966], the first rational approach to developing a method to predict ultimate load carrying capacity of a soil was provided by Terzaghi who recognized that if the three dominant factors contributing to bearing capacity, the weight of the soil, the effects of surcharge, and the strength parameter of the soil, could be assessed, a good estimate of bearing capacity would be obtained. Terzaghi chose as a model of the failure mechanism of the soil the solution to the problem of penetration of circular punches into metal as developed by Prandtl and Reissner. In the original solution Prandtl was able to neglect the effect of the weight of the metal moved to the influence of surface loadings on the surrounding material. When the material was assumed to be isotropic and homogeneous with no angle of internal friction, Prandtl's solution yielded,

$$q_d = \gamma D_t + 5.14c \tag{16}$$

On the basis of experiments and Prandtl's solution, Terzaghi and Peck [1948] derived the following semi-empirical equation for the bearing capacity of a circular footing.

$$q = 1.3c\, N_c + \gamma D_f\, N_q + .6\, \gamma N_\gamma \tag{17}$$

where q = pressure at surface to cause failure (psi)

c = cohesion or shear strength of the soil (psi)

γ = unit weight of the soil

D_f = depth of footing below the surface of the soil (in)

N_c, N_q, N_γ = factors which depend on the angle of internal friction and depth of footing

The first term represents a contribution due to the shear strength of the soil, the second the effect of material removed by putting the footing below the surface (equivalent to buoyancy in water), and the third term, the effect of an angle of internal friction (assumed to be zero for deep-sea sediments). The equation is modified slightly for square or oblong footings and Meyerhof [1961] gives constants for wedge and cone shaped footings. More complete discussions of the bearing capacity equation and slight variations in the values of the constants can be found in texts on soil mechanics [Terzaghi and Peck, 1943; Harr, 1966; and Hough, 1969]. Terzaghi's equation was the closest to Prandtl's (which requires theoretical failure surfaces) and it has been empirically verified for many years. It was therefore selected as a reliable relationship for estimating the static strength of deep-sea sediments. The values of the constants and the shapes used in equation (17) are given in Table I.

In the bearing capacity equation, the shear resistance mobilized on the failure surface of any surcharge material is neglected, hence the equation is conservative and relates only to events occurring below the footing or

penetrating object. During penetration, static resistance will occur in the undisturbed portion of the sediment below the deepest penetrating part, the other surfaces of the penetrating object are subjected to remolded sediment or sediment already set in motion by the penetrating object. Therefore the bearing capacity equation constants used in penetration prediction were considered to be for shallow footings for all depths of penetration.

3. The Character of Failure

Before a final method of solution was selected, motion pictures of penetrations into soft sediments and still photographs of soil failures were studied. In the motion pictures, the sediment was observed to move laterally outward from the object and have somewhat of a separation point from the object. While dropping plates vertically into a simulated sediment, Erchul [1968] found that polymer coatings to reduce drag on the plates had little effect at high entrance velocities and postulated that the sediment may not have been in contact with the plates. He also observed that at low velocities the lubricants did reduce adhesion to the plate and considerably greater penetration occurred with lubricated plates compared to unlubricated ones.

To find a qualitative indication of the effect of fluid in interstitial spaces, Rowe and others [1962] dropped probes into finely ground (less than 40 microns) silica dust. At atmospheric pressure the dust displaces laterally and craters were formed. In a vacuum with no air in the interstitial spaces, resistance to penetration was 100 percent

greater and the dust did not move laterally and no mounds or craters were formed.

The motion pictures of penetrating objects in the test pit revealed little splatter and little surface disturbance at a distance from the penetration point. Clark and Robertson [1965] observed motion pictures of a buoyant body exiting from water and came to the conclusion that energy lost due to surface effects was small. Moran [1965] also arrived at the same conclusion.

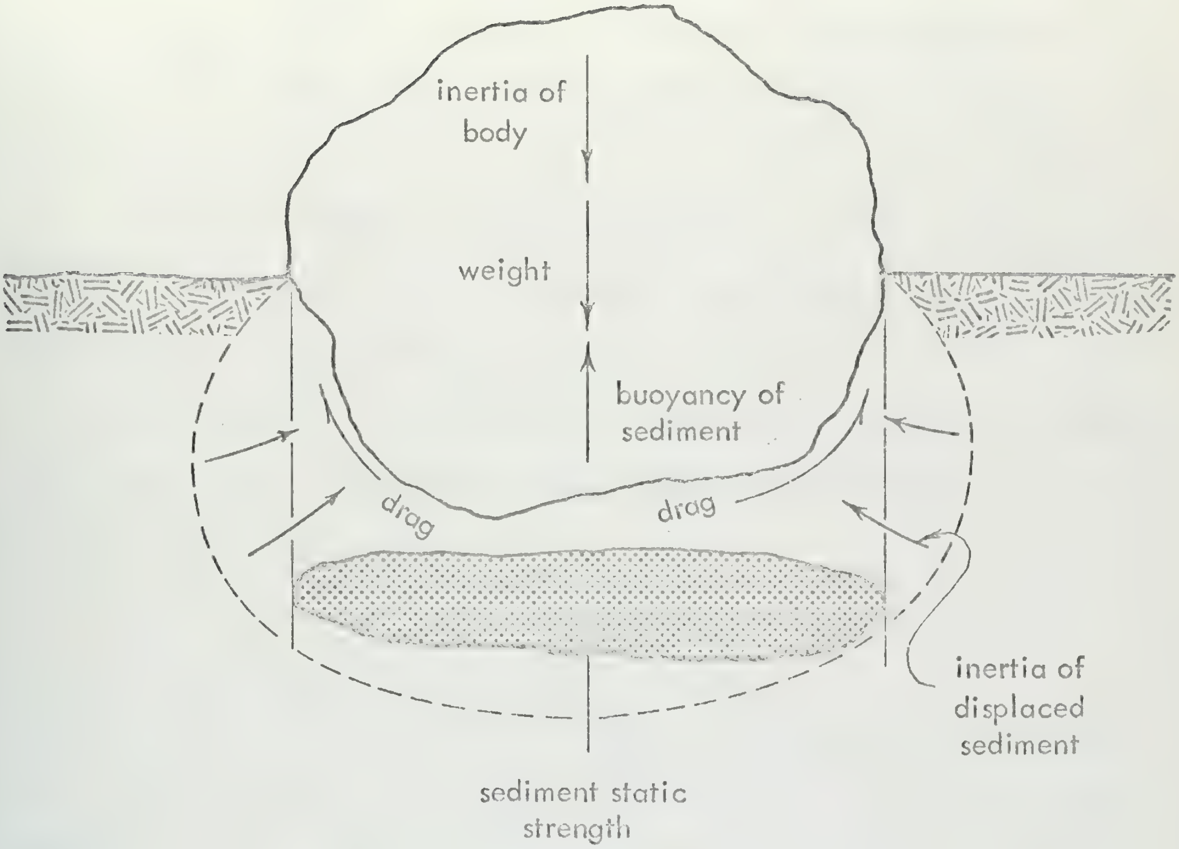
4. Equation of Motion

Since penetration is a dynamic phenomena involving the unsteady motion of a body, the first attempt at evaluating the penetration depth involved writing an equation of motion for the object as it penetrated the sediment. The final solution required a work energy approach that allowed the change in velocity and penetration depth to be determined incrementally with a computerized numerical scheme without the requirement to integrate the equation of motion and establish the instantaneous relationship between force, mass and acceleration.

The forces acting on an object penetrating a sediment characterized as a fluid with a static strength are shown in Figure 2. The equation of motion can be written as follows:

$$Ma = \sum \text{Applied Forces} \qquad (18)$$

Where the applied forces are: weight of the object, the sediment static strength, the buoyancy provided by the sediment, the force to overcome the inertia of the sediment, and the drag forces.



$$\underbrace{-M\ddot{x}}_{\text{body's inertia}} = \underbrace{Mg}_{\text{weight}} \underbrace{-\rho_0}_{\text{static strength}} \underbrace{-\gamma_s A x}_{\text{buoyancy}} \underbrace{-m'\ddot{x}}_{\text{sediment's inertia}} \underbrace{-\frac{1}{2} C_d A \rho_s \dot{x}^2}_{\text{drag}}$$

Figure 2. FORCES ACTING ON A PENETRATING OBJECT

The change of the body's motion as it penetrates the sediment is the equivalent of the resistance encountered by the body, or the energy involved in the change is equal to that expended in propelling the body. Momentum is transferred to a surrounding fluid by; (1) a certain volume of fluid being accelerated uniformly, (2) the fluid being put into turbulent motion, (3) compression waves, (4) gravity waves or spray [Hoerner, 1958]. All of the momentum is

eventually consumed by viscous friction. The last two modes of momentum transfer have been assumed to be negligible for the velocity ranges and object sizes under consideration and were discussed previously.

The treatment of the drag force, or the momentum put into the fluid by turbulent motion and viscous drag, outlined below, follows that given by Mandl and Givens [1964].

The drag forces cannot be evaluated easily for unsteady motion through a fluid boundary. The coefficient of drag can be approximated by;

$$C_d = \left(\frac{\beta}{Re} + C_{D_\infty}\right). \tag{19}$$

The first term represents the contribution due to viscous drag; the second is that due to form drag; β is a constant depending on the shape of the body and is usually represented by the first term in an infinite series (Oseen's approximation). For a circular disk placed broadside to a stream $\beta = \frac{64}{\pi}$, while for a sphere $\beta = 24$ (Lamb). The term C_{D_∞} corresponds to the asymptotic case as Reynolds number approaches infinity in Navier-Stokes flows, it depends on geometry and not the fluid dynamic properties. Inspection of experimentally obtained drag coefficients versus Reynolds number relationships for bluff bodies show that C_d is a slowly varying function at large Reynolds numbers. For bluff bodies with sharp edges nearly all the drag is form drag. The experimentally determined values of C_{d_∞} in the case of bodies with sharp edges is approximently 1.0. For bluff bodies without sharp edges, such as spheres, the form drag also depends on the position

of flow separation which in turn depends on the critical range of Reynolds numbers. The equation of motion then becomes:

$$(m'+M)\ddot{x} = Mg - p_o - \gamma_s Ax - \frac{1}{2} A \frac{\beta \mu}{D\rho_s \dot{x}} - \frac{1}{2} \rho_s A C_{d_\infty} \dot{x}^2 \qquad (20)$$

If the viscosity of clay is taken to be on the order of 3×10^{-3}, lbs - sec/in^2 [Whitman in Mandl and Givens, 1964], the Reynolds number for the objects that were under study with a three foot maximum dimension and with a velocity of ten feet-per-second, is on the order of 2×10^2. Admittedly a constant value of viscosity for a rheologically complicated substance such as a deep-sea clay is a gross over simplification, but the order of magnitude of the terms indicates that the viscous drag contribution to the equation of motion may be ignored [Mandl and Givens, 1964]. Also, towards the terminal phase of motion where the effect of viscosity is liable to increase rapidly with decrease in the rate of strain, the influence of viscosity will be negligible since the velocities are small and the other terms in the equation are larger by several orders of magnitude. Since form drag represents pressure forces on the body which are significant at the higher velocities, it could not be neglected.

5. Added Mass Effects

Another reason to treat the sediment as a fluid was to have a method available to estimate the volume and velocity of sediment displaced as the object penetrated. Womack [1967] verified that the amount of saturated clay moved during penetration was equal to the size of hole created.

The energy required to move the sediment is conserved since once the sediment is put in motion by the object it will continue to move away from the object creating a larger crater as the object is slowed by other forces. It is very important though, because the drag term of the equation of motion is dependent on velocity squared and the inertial effect of the sediment motion will alter the velocity-time history of penetration which has significant effects depending upon the shape and impact velocity of the object.

Added mass is caused by hydrodynamic pressure forces which are proportional to the instantaneous values of acceleration and according to Wendel [1950] appear to have the same value in a viscous or inviscid fluid as long as small bodies are not involved. The added masses were determined according to equations and methods given by Saunders [1957], which are tabulated in Table II.

The assumptions pertaining to the fluid approximation of deep-sea sediments can be summarized as follows and are the same as given by Moran [1965] in a study of water entry and exit.

1. Irrotational flow - viscous effects on the pressure felt by the body are generally small and the variations in inviscid forces are more important than viscous drag.

2. Incompressible flow - impact velocities are well below the speed of sound.

3. Surface effects are negligible.

The problem with determining depth of penetration from equation (20) is that it cannot be integrated during the unsteady motion of an object transiting a fluid boundary from one fluid to another. This is true for the following reasons: (1) m', the added mass and mass of the displaced sediment, is a function of depth of penetration for an object whose submerged portion changes shape as it submerges; (2) the dominant term, that of static soil strength, varies with the depth in a highly irregular manner; (3) the location of the air-to-sediment boundary condition is unknown a priori; and finally, (4) the flow is unsteady.

6. Transformation of the Equation to Work-Energy

The equation of motion may easily be resolved into an equation of energy and work which is time independent and a function of increments of distance. The development is given below.

$$\sum F_x = M \frac{d^2x}{dt^2} \tag{21}$$

Multiplication by dx gives

$$\sum F_x \, dx = M \, dx \frac{d}{dt} \left(\frac{dx}{dt}\right) = M \frac{dx}{dt} \, d \left(\frac{dx}{dt}\right) \tag{22}$$

The first integral with respect to displacement is:

$$\int F_x \, dx = 1/2 \; M \left(\frac{dx}{dt}\right)^2 + C \tag{23}$$

The left hand term represents the work done on M during the interval dx and can be evaluated if F_x is a known function of x. The right hand term represents the corresponding change in kinetic energy of the object.

Kinetic energy is a scalar quantity that depends only on the mass and magnitude of the velocity. Since the velocity is squared it is always positive. The total mechanical energy of the body is equal to:

$$E = KE + PE \tag{24}$$

For an object penetrating the sediment and coming to rest, the energy of the object can be accounted for by:

$$E_1 + E_{IN} - E_{OUT} = E_2 \tag{25}$$

This simple balance states that the total energy E_1 of the object at the beginning of an interval plus any energy put into the object minus any energy taken out must equal the final energy, E_2, of the object at the end of the interval. When the object has lost its energy in overcoming buoyancy, static soil strength, inertia of the sediment, and drag, it will stop its motion.

A particular reference level for the energies is not needed since energy is relative. The potential energy depends on an arbitrary selection of datum for zero potential. Also the kinetic energy is arbitrarily expressed relative to the condition at zero velocity. Hence any physical measurement over an interval describes a change in energy. It follows that reference to an arbitrary datum used for the expression of energy will cancel.

The work-energy method approach to solving a problem is powerful but dangerous because an answer is always obtained with no indication that the answer is correct. The method balances work to equal energy available and if a portion of

of the energy available is not considered, or incorrectly computed, work is still done and an answer results. In the unsteady case of penetration, using an iterative solution almost requires a computer because errors in computation will not be indicated but will appear as energy gained or lost. The answer will not appear wrong unless a gross error was made.

In analysis of the penetration problem only mechanical energy was considered, with the sediment and object being a conservative system in the gravitational field. Thermal, chemical, electrical and atomic energies were neglected.

7. Method of Solution Used with a Computer

The numerical iteration scheme used to solve the penetration problem was the same for each object shape. Briefly, it divided the object into sections or slices in the same plane as the sediment surface. Then the work necessary to submerge each section and the work done by the sum of the submerged sections, the forces due to the inertia of added mass and displaced mass of the sediment, the static strength of the sediment, and drag in moving an incremental distance equal to a section thickness were calculated and subtracted from the kinetic energy and change in potential energy of the object. Penetration depth was determined when the total kinetic energy of the object equaled zero.

A description in mathematical terms follows and a block outline of the computer solution is shown in Figure 5.

Constants and necessary approximations for each object are listed in Table I. The computer programs are included as Appendixes C through H.

Refer to Figure 3 for an explanation of the definitions that follow.

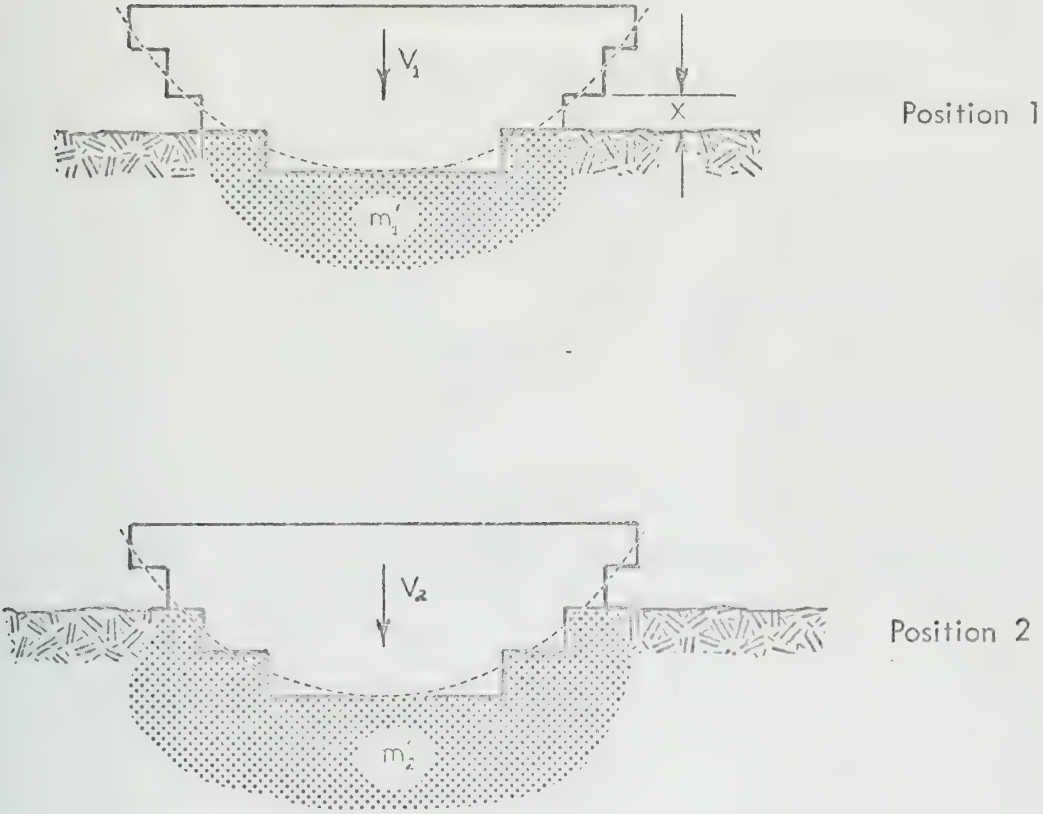


Figure 3. DEFINITIONS

v_1 = average velocity of the object as it transits distance x from position 0 to position 1. (Assumes a linear velocity gradient)

v_2 = average velocity of the object as it transits distance x from position 1 to position 2

M = mass of the object

m'_1 = added mass at section 1, plus the mass of displaced fluid at section 1

m'_2 = added mass at section 2, plus the mass of displaced fluid at section 2

$\Delta m = m'_1 - m'_2$

U = work done

U_b = work done against buoyancy forces as object transits from position 1 to position 2

U_s = work done against sediment static strength as the objects transits from position 1 to position 2

U_d = work done against drag forces as the object transits from position 1 to position 2

ΔU = the change in energy of the body as it transits from position 1 to position 2, not including change in potential energy

E_1 = total energy of the object at position 1

E_2 = total energy of the object at position 2

ΔPE = change in potential energy of the object over distance x

From equation (22)

$$U = \int_{v_1}^{v_2} m' \, v \, d \, v \tag{26}$$

$$U = 1/2 \; m' \; v_2^2 - 1/2 \; m' \; v_1^2 \tag{27}$$

it follows that

$$\Delta U = 1/2 \; m'_1 \; v_2^2 - 1/2 \; m'_1 \; v_1^2 + 1/2 \; m' v_2^2 + U_b + U_s + U_d \tag{28}$$

NOTE: 1. $\Delta m'$ was accelerated from a static condition, zero velocity to the velocity at the end of the section over which it was computed.

2. $\Delta m'$ was assumed to be zero after the object had penetrated to its maximum dimension since separation of the sediment from the object was apparent at this point.

The incremental distance, x, is fixed, and the various masses are known as is the work necessary to move the object from position one to position two. Velocity at position two is unknown. Therefore from the work energy relationship

$$E_2 = E_1 + PE - \Delta U = 1/2\ Mv_2^2 \tag{29}$$

Combining equation (28) with (23) and solving for v_2 gives

$$v_2 = \sqrt{\frac{2(\Delta PE + E_1 + 1/2\ m_1'\ v_1^2 - U_b - U_s - U_d)}{(M + \Delta m' + m_1')}} \tag{30}$$

In the iteration scheme, when v_2 equals zero, the sum of the increments, x, is the penetration depth.

The work done against buoyancy forces is a straightforward calculation that is discussed in elementary fluid mechanics texts. In the computer iteration scheme where the sections of an object are taken to be slices with vertical sides it becomes;

$U_b = 1/2\ \gamma\ A\ x^2$ (for the section being submerged)

plus $\sum \gamma\ A\ x^2$ (for all sections below the one being submerged)

The work done against drag forces was taken to be:

$$U_d = 1/2\ \rho C_{d_\infty}\ A\ v^2\ x \tag{31}$$

where γ = bulk wet density of the sediment

C_{d_∞} = drag coefficient for the approximate object shape that is below the sediment surface

A = the maximum cross sectional area of the object below the sediment surface and normal to the velocity vector

v = average velocity over the distance moved, assuming a linear variation in velocity.

The work done against the sediment static strength was calculated from the ultimate bearing capacity equation.

$$U_s = C_f N_c A c x \tag{32}$$

where C_f = a constant depending on footing shape

N_c = a constant depending on the type of sediment and footing profile

c = shear strength of the sediment

When the penetrating object had a flat plane forcing into the sediment such as a cylinder impacting on end, the cross sectional area, A, of the flat area and the shear strength, c, of the sediment at the penetration level of the flat area were used in the equation above. In the case of objects with rounded or sloping sides, a judgment had to be made of a cross sectional area and representative shear strength. The area selected was the maximum cross sectional area normal to the velocity vector at the surface of the sediment, or the maximum cross sectional area of the object if the area had penetrated beneath the sediment surface. This method of approximating a sloping or curved surface by a projected horizontal area appears valid for blunt objects [Meyerhof, 1967]. Since the shear strength characteristics of deep-sea sediments in the upper layers appear to change radically with depth in the sediment column, a shear strength for equation (32) was determined by selecting an average

depth according to the zones of plastic failure implied by equations (16) and (17). This was selected as one-half of the penetration depth until the maximum cross sectional area had been reached, then it became the depth of penetration minus one half the penetration depth when the maximum cross sectional area was coincident with the surface of the sediment as illustrated in figure (4).

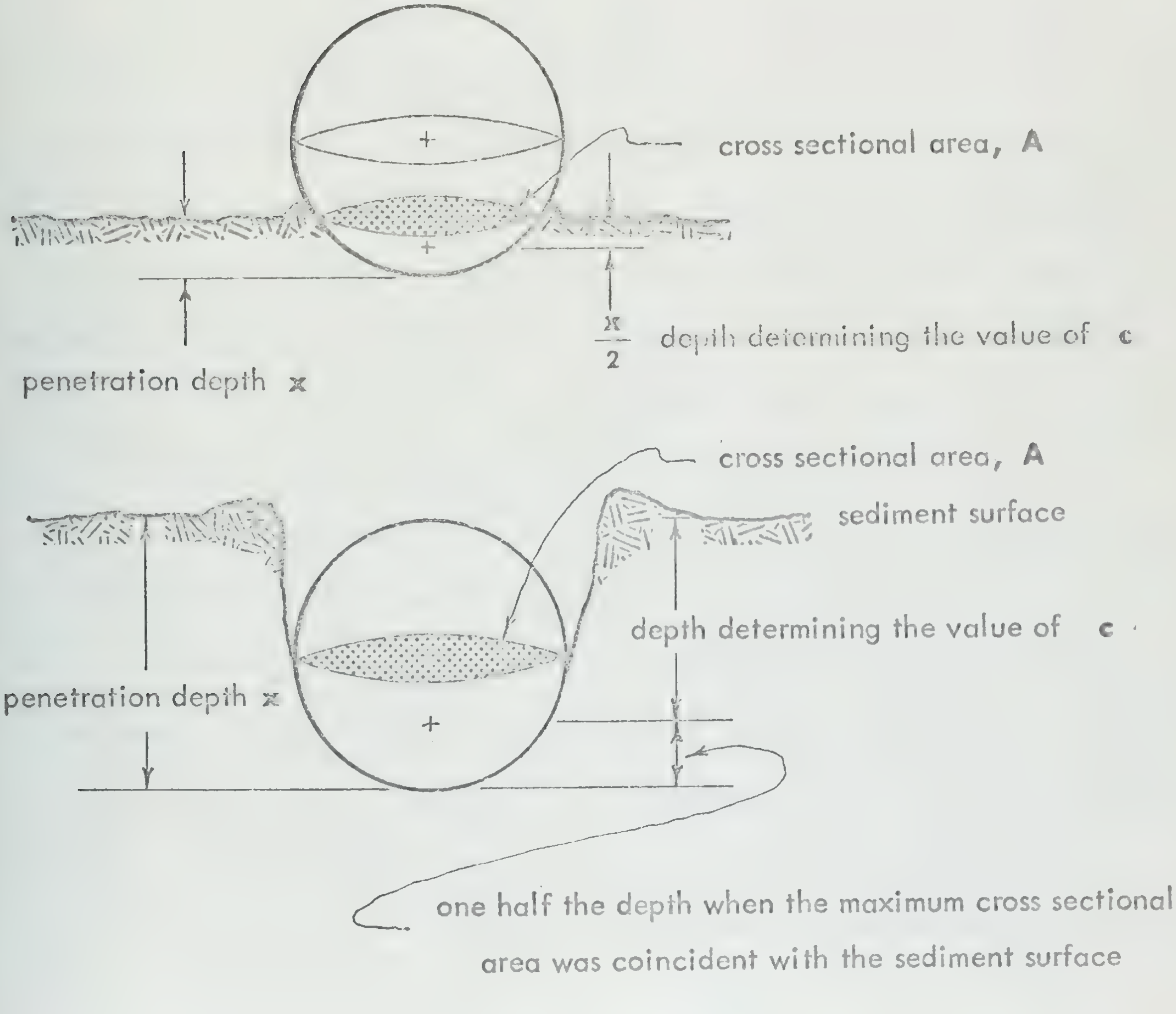

cross sectional area, A
$\frac{x}{2}$ depth determining the value of c
penetration depth x
cross sectional area, A
sediment surface
depth determining the value of c
penetration depth x
one half the depth when the maximum cross sectional area was coincident with the sediment surface

Figure 4. DETERMINING THE DEPTH OF "c" FOR NON-FLAT OBJECTS

The method described was adequate for curved and conical objects and approximates a representative strength in the theoretical zones of plastic failure in the sediment. An alternative and more refined method of selecting A and c, would have been to use the differences in the cross sectional area from section to section and apply the value of c at the depth of each section. This increased the complexity of the iteration procedure, hence was attempted only when there were discontinuities in the penetrating object's shape such as might occur with a truncated cone.

The distance of each iteration was chosen only to conserve computer time and approximate the expected accuracy of the field tests. Larger and smaller iteration intervals were tested for effects on the final depth and as long as the interval was less than one-half of the distance between shear strength measurements, convergence was always apparent. With a linear shear strength profile, the interval is limited only by the desired accuracy of the solution.

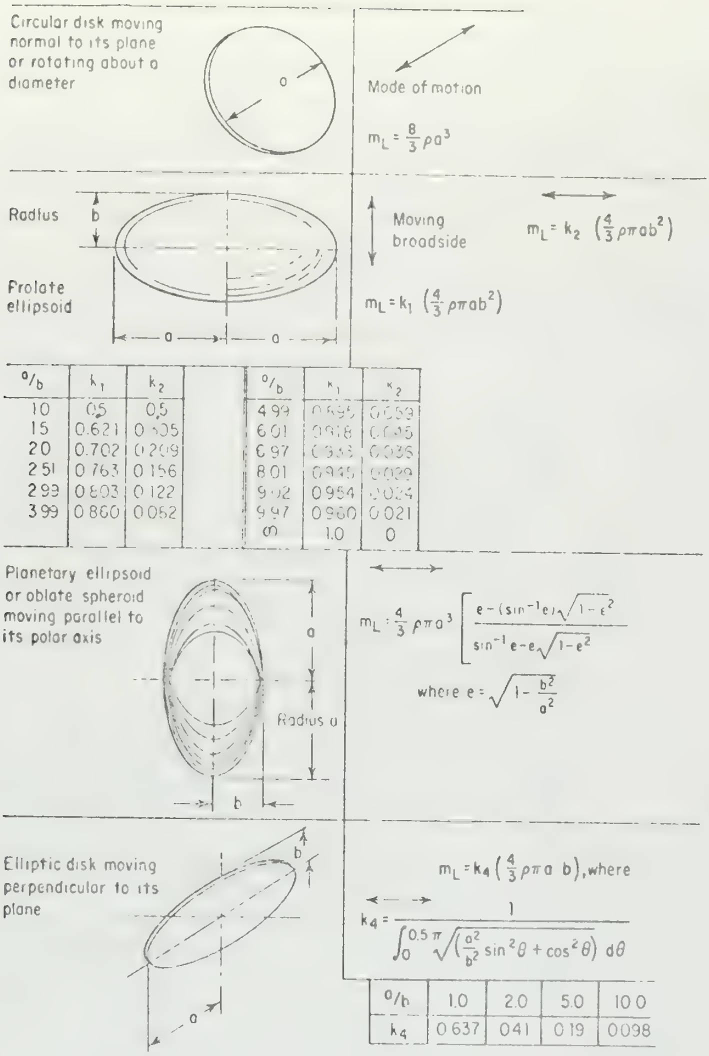
The equations for added mass are given in Table II. A flow chart of the basic program is given in Figure 5.

Appendix A presents a set of curves which qualitatively illustrate the relative influence of each force in the penetration equation. They were obtained by using the sediment shear strength profile typical of the world's deep-ocean basins as determined by Hoag [1970] and shown in Figure 13.

OBJECT	SECTION FORM	COEFFICIENT OF DRAG[1]	FOOTING SHAPE FACTOR[2]	BEARING CAPACITY FACTOR[2]	APPROXIMATION SHAPE FOR COMPUTING ADDED MASS
Sphere	Cylinder	0.3	1.3	5.7	One half of an oblate spheroid moving parallel to its polar axis
Horizontal Cylinder	Rectangular Parallelepiped	0.68	1.3	5.7	One half of a prolate ellipsoid moving broadside with projected area equal to the area of the section form with the same ratio of maximum and minimum dimensions
Cylinder-On-End	Cylinder	0.3	1.3	5.7	One half of a circular disk moving normal to its plane
Cube	Square	1.1	1.3	5.7	One half of a circular disk with an area equal to the area of a square moving normal to its plane
Rectangular Parallelepiped	Rectangular Parallelepiped	1.0	1.3	5.7	One half of an elliptical plate with the same area and ratio of maximum and minimum dimensions of the section form moving normal to its plane (k = .51)
Cone	Cylinder	0.3	1.0[3]	4.7[3]	One half of a prolate ellipsoid moving on its long axis (k = .095)

Table I. CONSTANTS AND SHAPES USED FOR COMPUTATIONS

(see next page for footnotes)


Circular disk moving normal to its plane or rotating about a diameter
a
Mode of motion
Radius
b
Prolate ellipsoid
a
a
Moving broadside
Planetary ellipsoid or oblate spheroid moving parallel to its polar axis
a
Radius a
b
Elliptic disk moving perpendicular to its plane
b
a

$m_L = \frac{8}{3}\rho a^3$

$m_L = k_2\left(\frac{4}{3}\rho\pi ab^2\right)$

$m_L = k_1\left(\frac{4}{3}\rho\pi ab^2\right)$

a/b	k_1	k_2
1.0	0.5	0.5
1.5	0.621	0.305
2.0	0.702	0.209
2.51	0.763	0.156
2.99	0.803	0.122
3.99	0.860	0.052
4.99	0.895	0.059
6.01	0.918	0.045
6.97	0.933	0.036
8.01	0.945	0.029
9.02	0.954	0.024
9.97	0.960	0.021
∞	1.0	0

$$m_L = \frac{4}{3}\rho\pi a^3\left[\frac{e-(\sin^{-1}e)\sqrt{1-e^2}}{\sin^{-1}e-e\sqrt{1-e^2}}\right]$$

where $e = \sqrt{1-\frac{b^2}{a^2}}$

$m_L = k_4\left(\frac{4}{3}\rho\pi a\ b\right)$, where

$$k_4 = \frac{1}{\int_0^{0.5\pi}\sqrt{\left(\frac{a^2}{b^2}\sin^2\theta+\cos^2\theta\right)}\,d\theta}$$

a/b	1.0	2.0	5.0	10.0
k_4	0.637	0.41	0.19	0.098

Table II. FORMULAS FOR CALCULATING ADDED MASS[4]

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[1] Hoerner, S. F., Fluid Dynamic Drag, Practical Information on Aerodynamic Drag and Hydrodynamic Resistance, Chap. II, Published by the author, Midland Park, New Jersey, 1958.

[2] Terzaghi, Karl and Peck, Ralph B., Soil Mechanics in Engineering Practice, p. 172, John Wiley and Sons, 1948.

[3] Meyerhof, G. G., "The Ultimate Bearing Capacity of Wedge Shaped Foundations", Proceedings, 5th International Conference Soil Mechanics and Foundation Engineering, v. 2, p. 106, Paris, 1961.

[4] Saunders, Harold E., Hydrodynamics in Ship Design, v. II, p. 421, The Society of Naval Architects and Marine Engineers, 1957.

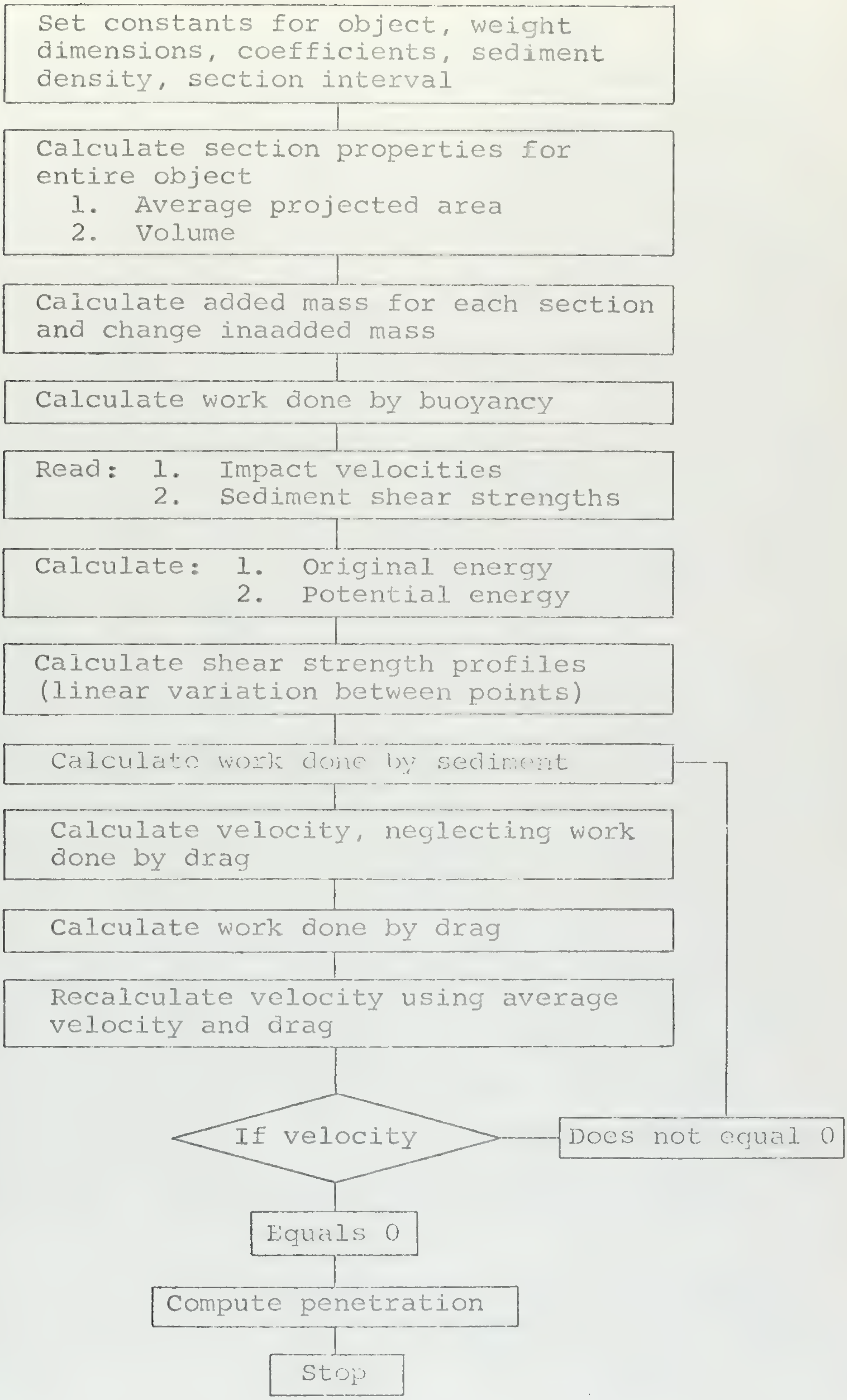

Set constants for object, weight dimensions, coefficients, sediment density, section interval
Calculate section properties for entire object
1. Average projected area
2. Volume
Calculate added mass for each section and change inaadded mass
Calculate work done by buoyancy
Read: 1. Impact velocities
2. Sediment shear strengths
Calculate: 1. Original energy
2. Potential energy
Calculate shear strength profiles (linear variation between points)
Calculate work done by sediment
Calculate velocity, neglecting work done by drag
Calculate work done by drag
Recalculate velocity using average velocity and drag
If velocity
Does not equal 0
Equals 0
Compute penetration
Stop

Figure 5. OUTLINE OF COMPUTER PROGRAM

C. MODIFICATION OF THE METHOD FOR USE AT SEA

The method was ultimately developed for general use at sea with as few restrictions as possible placed on size and shape of the object and on the type of sediment. However the only data available to test and verify the method was for an air-to-simulated deep-sea sediment case.

There are three relatively simple alterations that should be made to the computer program before it can be used in a water-to-sediment case. The three alterations should act to increase penetration depths at higher velocities and their overall effect is to increase the importance of an accurate determination of the shear strength profile.

First, the added mass effects will change by the ratio of the density of sea water to the density of the sediment. This can easily be accomplished by dropping the unit value of sea water from the bulk wet density term in the programs. Additionally, the added mass of the object free-falling through the water must be added to the total kinetic energy of the object at impact and a method for calculating the effect of this entrained water mass taken into account.

Second, the buoyancy term will also change by the ratio of the density of the sea water to the density of the sediment.

Third, the drag term will change by the ratio of sea water density to sediment density. Also a drag term must be included for the part of the body that projects above the sea-sediment interface. The easiest way to accomplish this

would be to include a drag term for the whole object and add a drag term for the portion of the object submerged in the sediment.

The three modifications will serve to reduce the influence of added mass, buoyancy and drag and cause the sediment static strength term to become even more dominant than in the air-to-sediment case. Keller [1964], used the standard bearing capacity equation, only, to predict the initial settlement depths of a rectangle, square, and cylinder into soft bay sediments. The results were poor and he concluded that problems with determining an accurate strength of the sediment were the reason his calculations always underestimated the settlement depth.

To correctly use the method at sea, several cores should be taken and their physical and mechanical properties averaged. Averaging should reduce errors caused by sampling and testing disturbances. The effect of sensitivity, as it applies to the shear strength used in computing penetration depth, is uncertain. Possibly the remolded shear strength is a better value if it is assumed that impact shock effectively remolds the sediment to an unknown extent. In sensitive sediment, a range of predicted penetration depths should be calculated according to the degree of sensitivity.

The orientation that the object has as it first starts to penetrate has a significant effect on total penetration. After free-fall in several thousand feet of water, the object may still be tumbling or oscillating if it is unstable.

Schmid [1966] found that a significant portion of a falling body's energy may be in its angular momentum which is not included in this method.

For these reasons when predicting penetration depths, a computer routine should be used to solve for a range of impact velocities, shear strength profiles, and object orientations. The calculations can be done by manually using larger intervals, as was done to check the first computer solutions, but since energies are being equated and the method is iterative, extreme caution must be used since an answer, correct or not, always results.

IV. RESULTS OF EXPERIMENTS

A. THE PROBLEM OF MODELING IN SOILS

Some problems with testing and modeling the dynamic behavior of soils are discussed before reviewing the data available to test the penetration prediction method and the results of the tests.

The field of soil mechanics has traditionally been concerned with large scale construction operations. Many of the methods used to calculate the stability of slopes and foundation designs are based on ultimate collapse criteria and much of what has been learned about soil behavior was derived from studies of catastrophic large scale failures. Big construction projects are seldom undertaken without expensive, full-scale, field tests of critical portions of the foundations, and modern buildings are carefully instrumented to monitor their settlement and reaction to seismic disturbances. A good indication of the state-of-the-art of soil mechanics is implied in the large safety factors recommended in texts and building codes. The lack of understanding is, in large measure, due to the inability to parameterize and model a substance as complex as a soil.

When the problem is narrowed to the field of saturated deep-sea sediments, the problems of modeling are somewhat reduced. A modeling approach to investigate the dynamic response of soils to impulsive loads was conducted by Westine [1966] who found that a satisfactory case could be made for

a model with saturated clays, but granular materials with angles of internal friction were impossible to simulate, since dilation and pore water pressures were hard to model. Frolich [1967] attempted to model the dynamic behavior of submarine sediments, but unfortunately he passed away before publishing his final results.

There are several areas where modeling dynamic penetration phenomena in deep-sea sediments may prove to be impossible.

Under dynamic loads a saturated deep-sea sediment may behave as a bingham body. The inertial resistance of the sediment to deformation coupled with the threshhold stress, or static resistance of the sediment, may be very hard to separate if the mass and therefore, inertia, of the penetrating body is small or on the same order of magnitude as the static resistance and inertial resistance of the soil. An analogous problem, but simpler by one factor, is unsteady fluid flow at low Reynolds numbers where inertial and viscous forces are the same order of magnitude. In the dynamic testing of soils this problem can be circumvented by full-scale tests using objects with large masses.

A similar problem involves surface effects and the adhesion of deep-sea sediments to an object. The effects of adhesion have been shown to be influenced by polymer coatings, surface roughness, surface chemical composition, etcetera, by Erchul [1969] and other investigators studying pile driving on land. Surface effects may control penetration

significantly if the object has a large surface area in relation to its total mass. A means of minimizing adhesion effects would be full scale tests with large masses.

If a study's purpose is to learn more about adhesion, or mass effects, then modeling may be the best approach. However extrapolation of modeled test results to objects larger by an order of magnitude may be invalid.

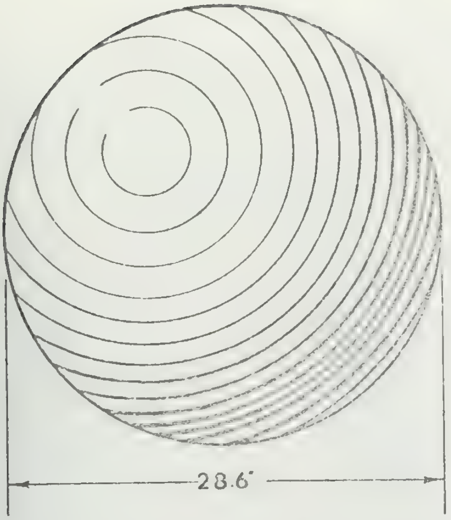
Finally, when attempting to model a sediment composed of clay particles which are very small, to reduce them further by an attempt at modeling the interparticle attractive forces and pore water viscous effects, may be impossible. Also, the instruments available to measure the modeled sediment strength may not have the required accuracy or precision for a reduced scale.

B. DATA AVAILABLE

The Naval Ordnance Test Station, Pasadena, California, constructed a large pit from sheet piling, 37.5 feet in diameter, and filled it to a depth of 16 feet with a very weak sediment from Seal Beach Lagoon, California. The pit was used to conduct tests on the holding strength of anchors, breakout forces of objects imbedded in the mud, and experiments with dynamic penetration. The penetration experiments were carried out under the direction of Dr. R. J. Smith in September, 1965. The penetration experiments are described below.

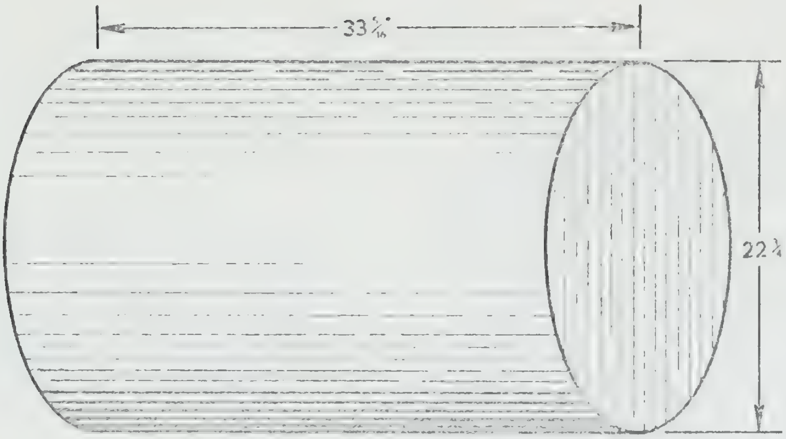
1. Description of Objects and Tests

Figures 6 through 11 show the six different objects that were dropped into the test pit. All six were fabricated



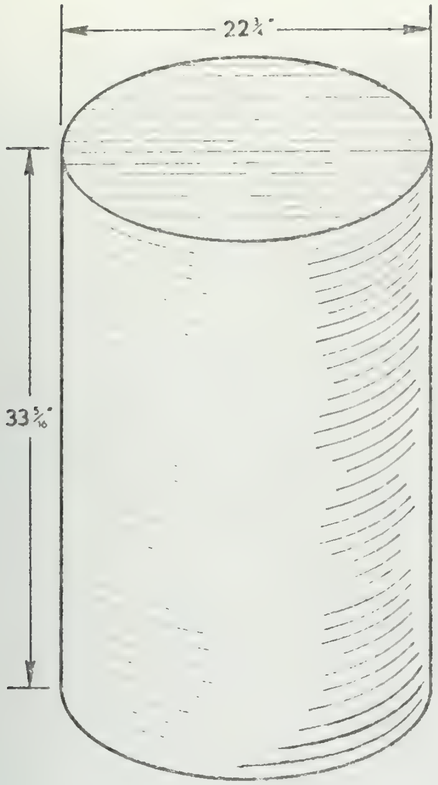
The sphere was made of a heavy steel plate and weighed 561 pounds in air. A padeye provided an attachment point for lifting.

Figure 6. SPHERE



The horizontal cylinder was made from a 55 gallon oil drum. It weighed 540 pounds in air. It was lifted by a two pennant bridle with one pennant welded at each lip.

Figure 7. HORIZONTAL CYLINDER



The cylinder-on-end was also made from a 55 gallon oil drum. For the first tests it weighed 540 pounds in air. Later a flat, round plate was welded over the lip of the drum at the end that penetrated, making it smooth to reduce the amount of air that might have been trapped there. The plate increased the weight to 561 pounds in air. The drum was lifted by a three pennant bridle attached to its upper end.

Figure 8. CYLINDER-ON-END

The cube was fabricated from steel plate and weighed 702 pounds in air. It was lifted by a four pennant bridle to each corner of one face.

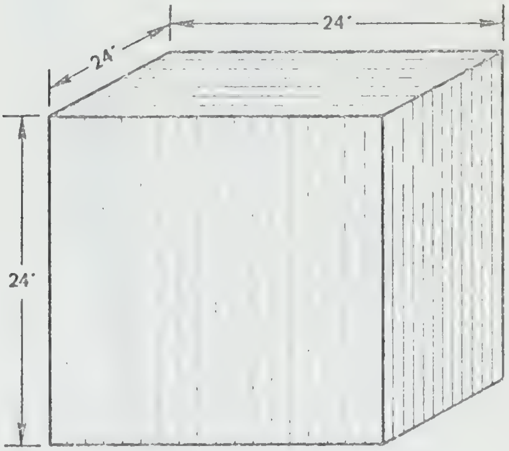
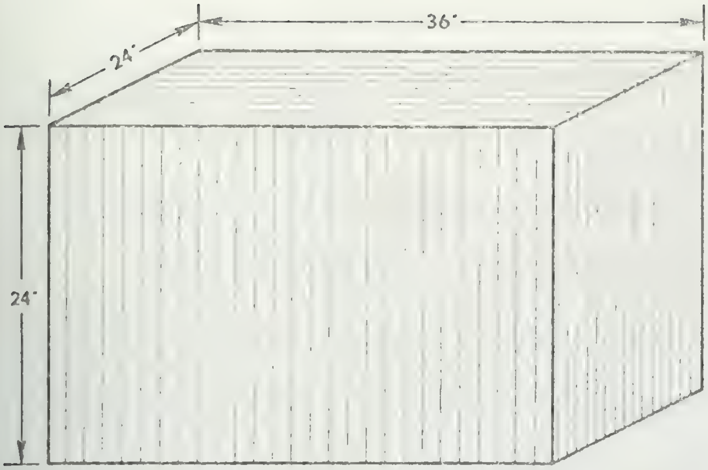


Figure 9. CUBE



The rectangular parallelepiped weighed 1,014 pounds in air. It was constructed of steel plate and lifted with a four pennant bridle to four corners of a large side.

Figure 10. RECTANGULAR PARALLELEPIPED

The cone was fabricated of steel plate and weighed 1,127 pounds in air. It was lifted by a three part pennant to the flat side and dropped point down.

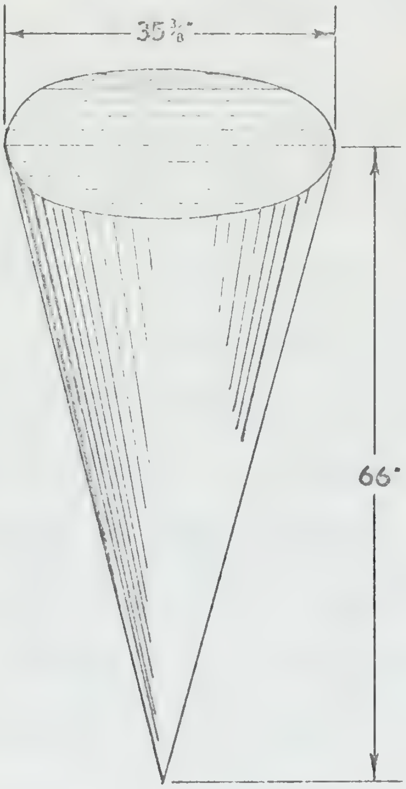


Figure 11. CONE

with a steel shell for structural rigidity and the cavity of the shell was completely filled with fresh water for weight. The weight could be changed if desired, however for penetration tests they were pressed full at all times. Dimensions of the objects are shown in inches.

The objects were suspended by a crane over preselected stations in the mud pit. They were released by a quick release hook that was tripped manually by pulling a line from the side of the pit. The objects were released at different heights above the mud-air interface to allow them to reach velocities of 5, 10, 15, and 20 feet per second as the object's lowest portion contacted the sediment-air interface. The zero velocity test was considered to be a zero release height, and the object was released with its lowest portion just in contact with the sediment-air interface.

Slow motion pictures, 32 frames per second, of almost all the penetrations were available. They were carefully studied in a frame-by-frame projector to double check the rough data sheets for height of drop and penetration depth. The movies also gave an indication of the stability of the object as it penetrated. Remarks about each penetration are given in Table X. Times for penetration and times for rebound were estimated by counting the frames of the movie film for each event. The movies confirmed the observations of Chuang [1970] that air trapped below a body impacting on a fluid does not alter the penetration depth. Any air that was trapped below the body usually vented by bubbling up

alongside the object after it had come to rest. Only in one or two cases was it observed to form a jet with a significant amount of entrained mud.

The penetration depth was determined by visual observation of marks painted on the objects which were scales divided into one quarter inch increments. The depth reference was the undisturbed surface of the pit. Depth observations were made at each corner of the rectangular objects and at a diameter of the axisymmetrical objects. The penetration depth was considered to be the numerical mean of the several measurements. Any exceptions to this method and angles of tilt at the object's final rest position are noted in the remarks column of Table X. The exceptions occurred when the cylinders-on-end tipped completely over after coming to rest. The penetration before tipping was used if it could be read from the movies with an accuracy of one half inch.

2. Description of the Sediment

There was a real problem finding a suitable material to simulate a true deep-sea sediment, compounded by the 700 cubic yards of material required to fill the test pit. The material selected was lagoonal mud, described as "unconsolidated grey sediment with medium sand sized mica flakes", from the tidal flats of Seal Beach Lagoon. Tables III through V contain detailed analysis of its mechanical properties, and mineralogical and chemical analyses of the lagoonal mud from samples taken from the borrow pit. A year after the penetration tests were completed, Muga [1966], while measuring

TABLE III. MECHANICAL PROPERTIES OF THE SEDIMENT IN THE TEST PIT[5]

Depth (in)	0-3	4-7
Color (GSA No.)	5GY 6/1	5GY 6/1
Odor	H_2S	H_2S
Bulk Wet Density (gm/cc)	1.452	1.559
Vane Shear Strength (psi)	0.364	1.495
Remolded Strength (psi)	0.364	1.736
Sensitivity	1.0	0.9
Water Content	82.9	66.3
Specific Gravity of Solids	2.914	3.019
Dry Density (gm/cc)	0.794	0.937
Void Ratio	2.676	2.226
Porosity (%)	72.8	69.0
Saturated Void Ratio	2.416	2.002
Organic Carbon (%)	1.385	0.578
Percent Sand	6.0	2.0
Percent Silt	30.0	18.0
Percent Clay	64.0	80.0
Median Diameter (mm)	0.0020	0.0018

Note: Samples were obtained with a two and one-half inch core liner from the site where the sediment originated.

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[5] Samples collected by R. J. Smith and analyzed at the Naval Civil Engineering Laboratory in Port Hueneme.

TABLE IV. MINERALOGICAL ANALYSIS OF THE TEST PIT SEDIMENT[6]

COARSE SILT TO SAND	PERCENTAGE
Quartz	15.39
K-Feldspar	7.69
Calcite	3.36
Opal	1.47
Muscovite (illite)	11.54
	Total = 39.45 percent
ACTIVE CLAYS	
Kaolinite	16.31
Mixed Layer	29.27
	Total = 35.58 percent
INACTIVE SILT TO CLAY SIZES	
Goethite	5.83
Halite	4.53
Organic	4.41
	Total = 14.77 percent

Note: The mixed layer was composed of 67 percent montmorillonite and 33 percent chlorite. The muscovite was chiefly terrigenous (clastic) and occurred in coarse silt-sized grains. The analyses were made by a combination of x-ray diffraction, chemical, and petrographic methods. Infrared absorption analyses and differential thermal analyses were used to obtain supplemental data. The values shown are recomputed to 100 percent and are reliable to about ±15 percent.

---

[6] Whelan, J. A., A Report on Mineralogy of Ocean Bottom Sediments, p. 10 unpublished report to the Naval Civil Engineering Laboratory, September, 1967.

TABLE V. CHEMICAL ANALYSIS OF TEST PIT SEDIMENT[7]

OXIDE	PERCENTAGE
SiO_2	48.34
$Al_2 0_3$	18.26
$Fe_2 0_3$	7.88
MgO	2.98
CaO	1.92
K_2O	2.74
Na_2O	3.02
H_2O	2.78
L.O.I.	9.67
Total	97.59
Surface H_2O	73.01

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[7] Whelan, op. cit., p. 8a.

TABLE VI. RANGE OF VARIATION OF TEST PIT SEDIMENT[8]

"The main feature of the soil is its highly variable properties, being both nonhomogeneous and nonisotrophic. Some of the variations are indicated below.

RANGE OF VARIATION (42 TESTS)

	MINIMUM	MAXIMUM	AVERAGE
Vane Shear Strength (psi)	0.0	1.050	0.530
Remolded Strength (psi)	0.0	0.861	0.390
Original Water Content (%)	43.5	79.6	63.5
Void Ratio	1.104	2.126	1.710
Porosity	52.5	68.0	61.9
Liquid Limit	41.0	68.0	56.1
Plastic Limit	27.5	43.4	34.2
Liquidity Index	70	255	136
Percent Sand	1.7	25.5	10.2
Percent Silt	30.8	54.4	40.5
Percent Clay	35.8	66.0	46.4

"In addition, soil samples were subjected to numerous triaxial, permeability and viscosity tests. From these tests it was determined that; (i) the yield strength of the 'soil' is approximately 0.5 psi; (ii) permeability is practically nil; (iii) cohesion, c, is almost zero; (iv) angle of internal friction is almost zero and (v) viscosity is independent of the rates of shear or deformation (i.e., rpm)."

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[8] Muga, J., Breakout Forces, p. 4, U. S. Naval Civil Engineering Laboratory Technical Note N-863, Port Hueneme, September, 1966.

break out forces in the test pit, conducted more tests to verify the mechanical properties of the sediment. Table VI is a summary of Muga's tests. It is obvious that the lagoonal mud was not uniform but characterized by variability, but a major cause of the variability was undoubtedly the result of sampling disturbances and continual reworking. Muga also stated that the mean viscosity was 300 square feet per second. This value represented a series of measurements taken with a commercial rotating-type viscometer. He did not attempt to correlate the viscosity with the vane shear strength because of the "marked variability in the soil properties". Since the sediment contained approximately 40 percent silt to sand sizes, there was certainly some angle of internal friction caused by these large sizes and this was probably the reason Muga found a high viscosity measurement. It also appeared that there were more coarse grain sizes present a year after penetration tests were conducted which indicated possible contamination with other material. For this reason Muga's values were not taken as absolutely correct, but they were included to illustrate the variability of the sediment used for the tests.

Figure 12 shows the mean shear strength profile of the sediment from 550 measurements. Although the mean strength profile is not representative of the average shear strength profile for the world's deep-ocean basins shown with a solid line, Figure 12, from Hoag [1970], it is remarkably close to the shear strength profiles of the edges

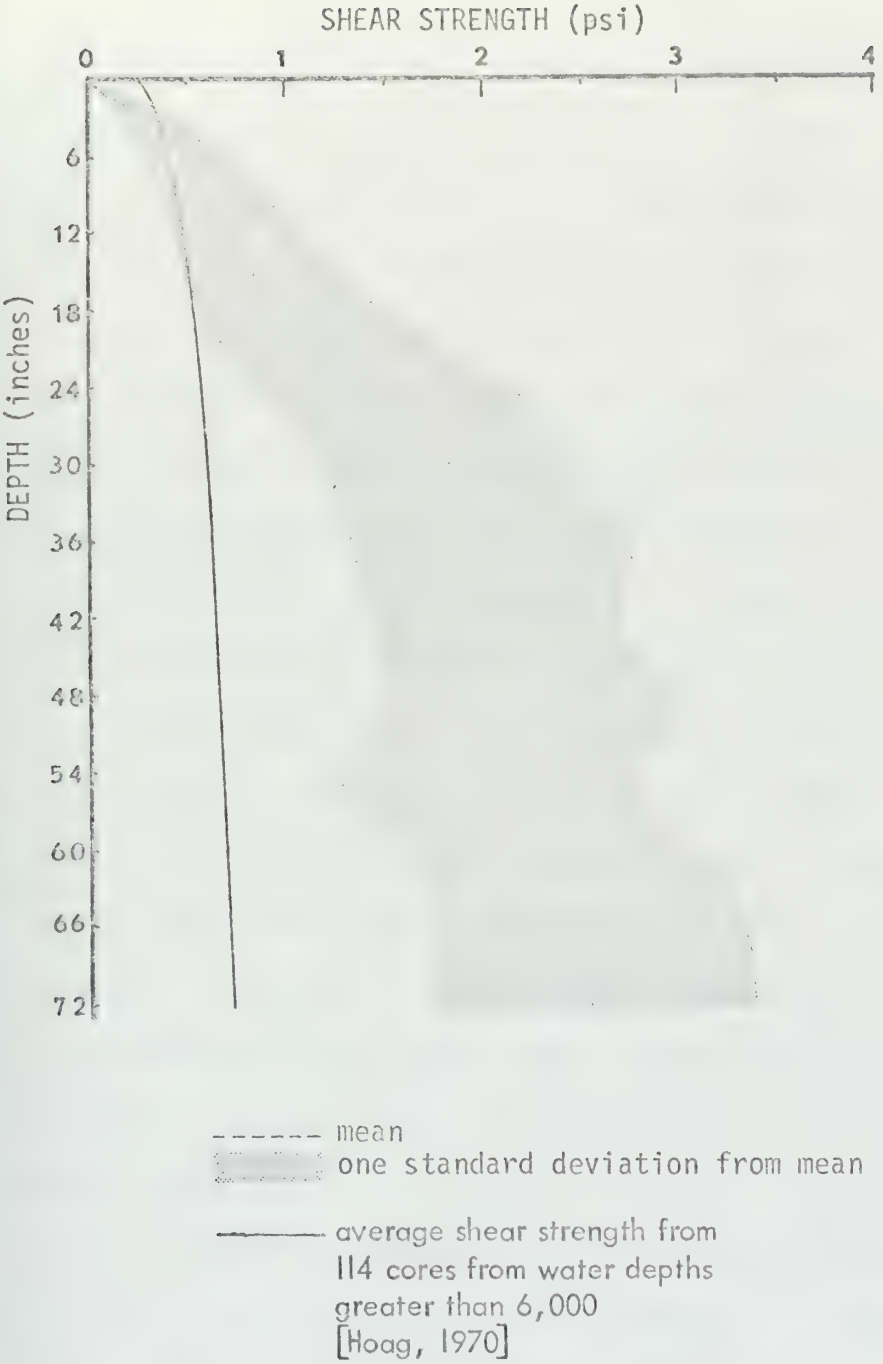
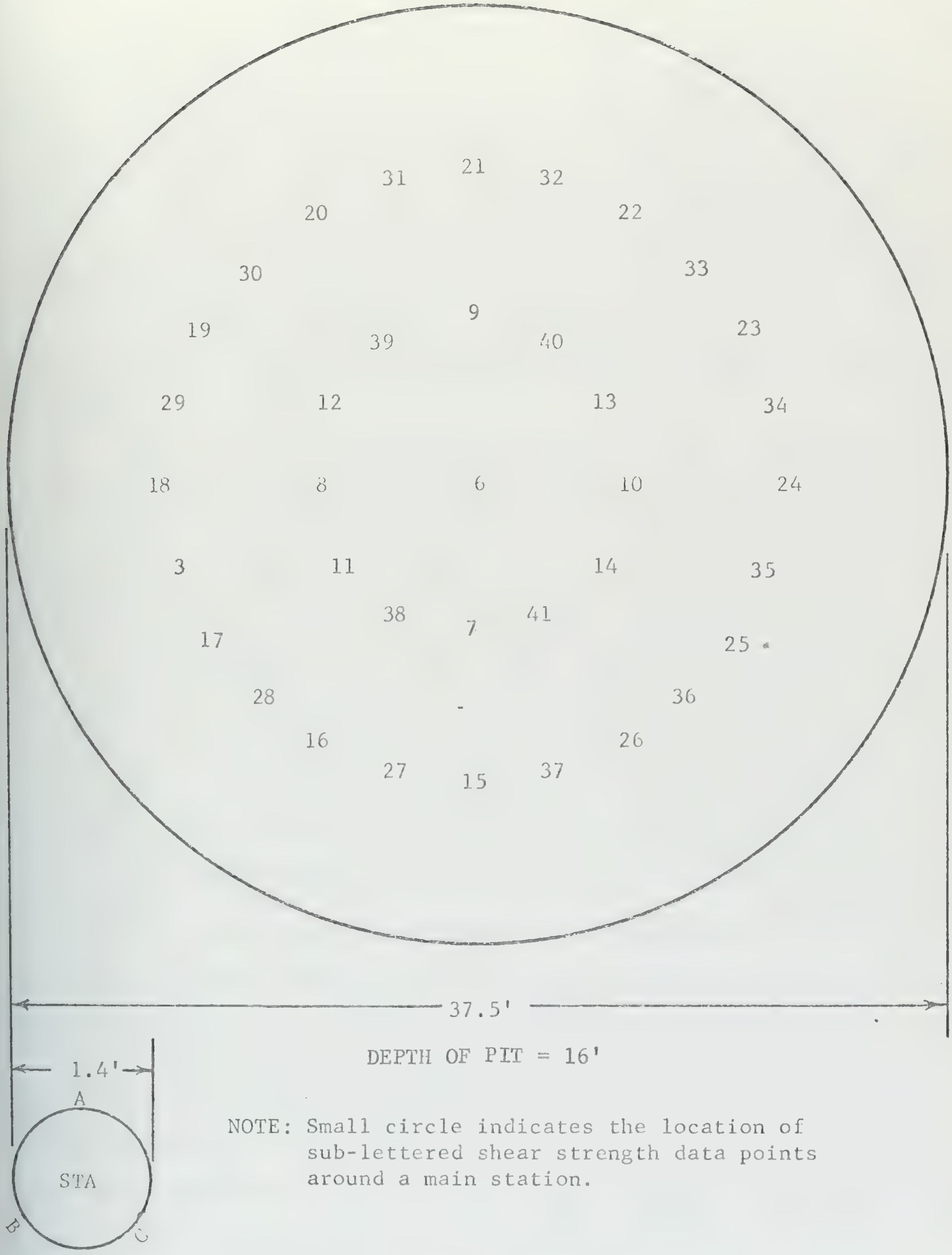


Figure 12. TEST PIT MEAN SHEAR STRENGTHS

of the Zigsbee Abyssal Plain as shown by Bryant and others [1967].

The numbering system designating the location, or station, where each penetration test was conducted is shown in Figure 13. The shear strengths at each station were taken using a two inch by five inch vane. The vane was operated by hand from a punt floating on the surface. It was driven into the sediment in six inch increments and torque applied by hand with a standard torque wrench and the maximum torque, converted to shear strength, recorded. Not all of the vane tests were conducted in the presence of an engineer and some were done by different personnel. Generally the shear strength profiles are consistently similar, with some erratic points, but there is some correlation between very erratic profiles and the date of tests, which indicated operator skill and care may have had an influence. The method of obtaining shear strength values greatly influences the value obtained according to Terzaghi [1960] and it was difficult to get consistent readings from an unstable punt with no control on the vane's rotational speed.

Other methods of determining shear strength profiles in the mud pit were considered, but rejected for the following reasons. In 1965, the existing penetrometer probes related resistance encountered to shear strength by empirical tables or graphs, and the very low strength of the mud pit was out of the empirical range. The use of these devices would have required modifications of the instruments and



NOTE: Small circle indicates the location of sub-lettered shear strength data points around a main station.

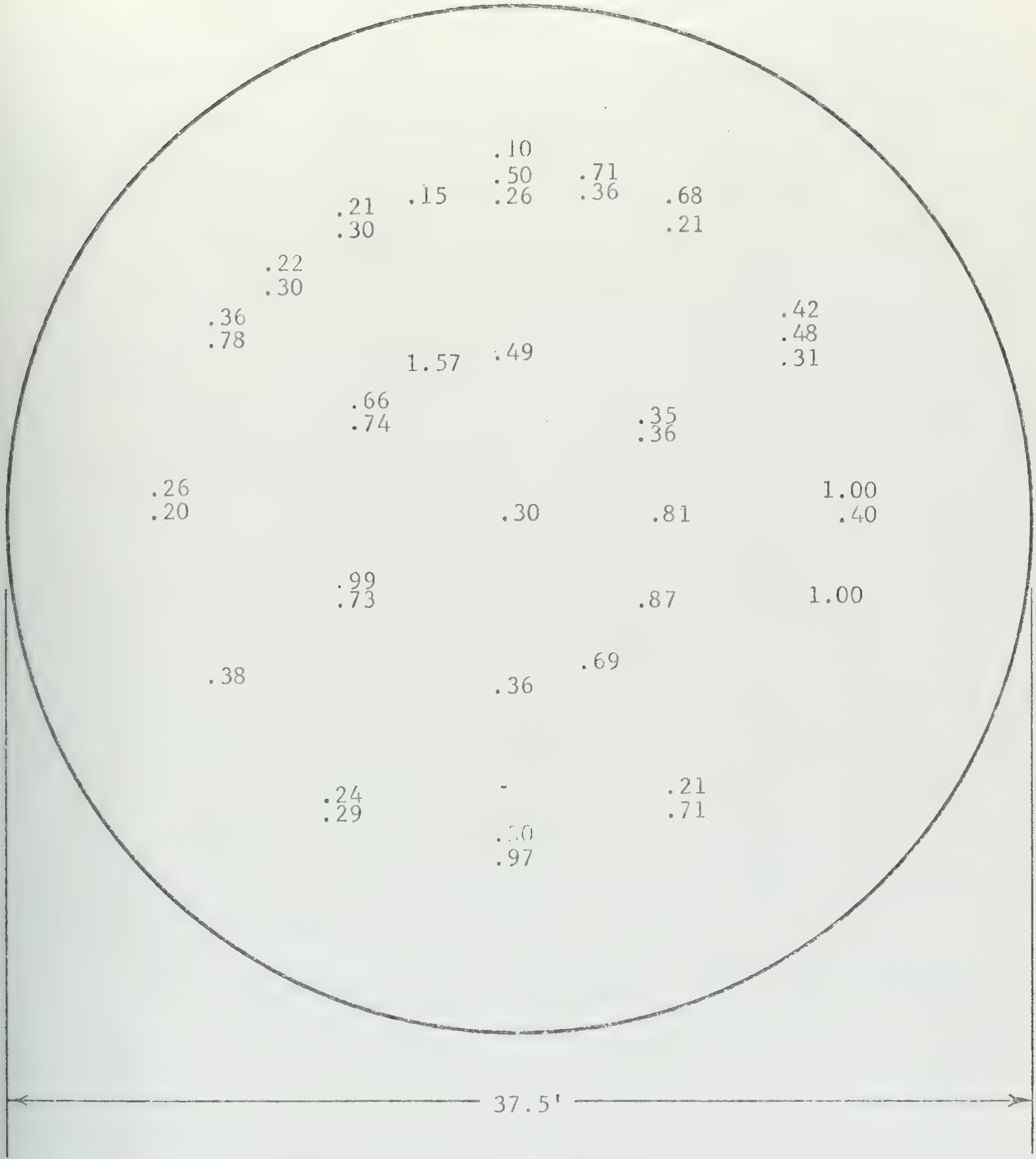
Figure 13. LOCATION OF DROP STATIONS IN THE TEST PIT

extensive testing to obtain empirical relationships. Second, the sediment in the mud pit probably had some slight but unknown angle of internal friction and the vane test measures a cohesive shear strength which is influenced by the angle of internal friction in a minor way. However, the vane test seemed the most practical test for shear strengths in cores and in-situ testing. Therefore, vane shear strengths were used exclusively to keep the results comparable to a real situation.

The horizontal variability of the observed shear strengths at six inch depths is shown in a plan view of the mud pit, Figure 14. The measurements taken on different dates in the same location also show a spread in values.

The variability of the shear strength in the mud pit was probably not random for the following reasons.

1. The huge volume of material required to fill the pit necessitated handling by large construction equipment which could have scooped up isolated chunks of material and allowed them to be placed in the pit essentially undisturbed, while most of the sediment was greatly disturbed during excavation, hauling and placement. The very high shear strengths have been attributed to the relatively small vane coming in contact with one of these hard chunks. The chunk would not necessarily affect penetration depth unless an object was dropped very close to one because the sediment was incompressible and moved as a unit. Most of the objects were large compared to the chunks or vertical distance between anomalously high observed shear strengths.



NOTE: More than one value indicates measurements were taken on different dates.

Figure 14. SHEAR STRENGTHS AT SIX-INCH DEPTHS PLOTTED ON A PLAN VIEW OF THE TEST PIT (psi)

2. Although it was not noted in the analysis of the sediment, some organic material or foreign objects may have been present since no special precautions were taken to sieve the sediment while it was being placed.

3. The extremely low values of observed shear strength may be attributed to the method of handling the sediment after a penetration trial. The holes made by the objects and other experiments with the sediment were smoothed over, filling depressions with a shovel and rake. Then shear strengths were taken at each station and penetration drops conducted at a later time. After all the stations had been used, the procedure was repeated. Since other tests were being conducted concurrently, the hole filling and smoothing was a continuous operation. Undoubtedly some very soft material and water accumulated at the bottoms of the holes and this accounts for the anomalously low shear strengths at considerable distances below the surface.

The low sensitivity of the sediment before sampling and the continual reworking it underwent while tests were in progress, led to the conclusion that the sediment used for the tests had a sensitivity of one and that the observed in-situ shear strength of the sediment was a good representation of its actual in-situ strength, if the problems of test operator error and the anomalous points due to hard chunks or soft spots could be resolved.

Fortunately, enough data, 716 points, existed to make a statistical analysis and a mean strength profile of the

mud pit. Table VII includes a matrix of all the observed shear strengths. The anomalously high and low values were identified by eye. Since the profile should have been fairly smooth with all the reworking the sediment underwent during placement and tests, the hard and soft spots were easily selected by visual inspection. The values considered anomalous are underlined in Table VII.

The mean and standard deviation of shear strengths as a function of depth, both with and without the anomalous values, are listed in Table VIII. It should be noted that the anomalous values often cause the standard deviation to more than double. The mean shear strength profile of the mud pit and one standard deviation calculated without the anomalous points are shown in Figure 12.

At each station the anomalous points were adjusted to fit a smooth profile that generally was within one standard deviation of the mean. The adjustment process was again subjective, as the precision of the original data did not warrant a more sophisticated approach. The observed shear strengths for each station were plotted with the mean profile. Then the anomalous points were moved to fit a general smooth trend of points within one standard deviation from the mean. The figures in Appendix B illustrate the adjustment at each station and the solid line is the actual shear strength profile used by the computer solution to predict penetration depth.

The shear strength and standard deviation value at the air-sediment interface was taken to be zero, in that sea

VELOCITY ft/sec	STATION	DEPTH 6"	12"	18"	24"	30"	36"	42"	48"
SPHERE									
0.0	6	.30	.38	.78	.70	1.34	1.63	1.53	1.55
5.0	7	.36	1.04	1.03	1.56	4.00	6.53	4.17	2.16
10.0	9	.49	.77	.85	5.58	4.14	1.91	1.91	1.77
15.0	20	.30	.12	.45	2.44	2.78	2.78	5.75	3.14
20.0	26	.71	.71	3.14	1.74	2.09	2.21	2.38	2.30
5.0	15	-	.52	1.08	1.51	1.74	1.95	2.11	2.44
10.0	-	.69	.66	.52	1.39	1.56	2.05	2.44	3.01
15.0	-	-	.36	.91	1.39	1.74	1.57	2.05	2.70
20.0	-	-	1.04	1.74	2.29	1.76	4.87	2.70	2.79
HORIZONTAL CYLINDER									
0.0	23	.42	1.74	2.38	1.57	7.31	10.11	5.57	3.84
5.0	15	.97	1.25	1.08	1.88	2.04	1.96	2.38	5.22
10.0	21	.26	.68	1.24	4.18	2.44	1.76	2.33	2.75
15.0	16	.29	.52	.17	.29	.76	2.16	1.74	1.76
20.0	22	.68	.73	1.74	2.16	2.45	3.86	2.58	3.84
20.0	12	1.74	2.18	2.78	1.22	1.01	1.74	1.30	.69
CYLINDER ON END									
5.0	-	-	.61	1.39	2.09	2.44	7.27	5.15	-
10.0	-	.37	.54	1.04	1.36	2.44	2.78	5.21	4.80
15.0	-	.52	.78	1.91	3.82	2.36	2.01	2.11	1.97
20.0	-	.69	1.81	1.43	1.06	1.97	1.57	1.65	1.76
0.0	22	.21	.35	.52	1.10	3.12	2.78	2.56	3.10
5.0	14	.87	1.04	1.04	1.41	1.13	1.48	1.87	1.76
10.0	16	.24	.33	.71	.87	1.74	1.74	1.79	1.81
15.0	12	.66	1.76	2.21	.87	.83	1.57	1.43	.42
15.0	21	1.03	.75	1.18	1.37	1.53	2.26	1.91	2.02
20.0	11	.73	1.27	.99	.52	1.52	1.91	1.39	3.96

NOTE: (1) A SINGLE DASH INDICATES MISSING DATA

(2) UNDERLINED VALUES WERE CONSIDERED ANOMALOUS

Table VII. SEDIMENT VANE SHEAR STRENGTHS IN THE TEST PIT

VELOCITY	STATION	DEPTH											
ft/sec		6"	12"	18"	24"	30"	36"	42"	48"				
CYLINDER ON END (CONT)													
5.0	20	.21	.31	.31	1.44	1.44	2.44	5.54	2.44				
10.0	25	.21	.57	1.46	2.11	2.05	2.07	2.09	6.26				
15.0	19	.36	.45	.40	1.22	1.39	1.74	2.35	4.45				
20.0	35	1.81	1.04	1.39	2.26	2.32	3.50	2.79	1.91				
CUBE													
5.0	-	1.01	1.04	1.76	.87	1.23	1.53	.56	.35				
10.0	-	1.06	.71	1.01	2.68	6.92	2.10	2.38	2.10				
15.0	-	.61	.72	3.43	2.97	1.83	1.74	1.55	1.60				
20.0	-	.75	1.29	.52	.66	2.83	5.07	6.95	3.04				
RECTANGLE													
0.0	24	1.39	.71	1.04	.52	1.74	2.12	2.78	2.87				
5.0	13	.35	1.02	1.37	2.68	2.99	5.87	3.65	2.77				
10.0	11	.99	.68	.71	1.70	1.74	2.07	1.95	3.13				
15.0	17	.38	.69	.69	1.56	2.00	3.48	5.93	4.35				
15.0	19	.78	.33	.35	.69	1.74	6.10	4.86	3.91				
20.0	18	.26	.35	1.31	.78	1.56	3.30	4.52	2.44				
CONE										54"	60"	66"	72"
0.0	23	.31	.35	.52	.75	.95	2.78	1.71	2.61	3.36	2.61	2.70	2.96
0.0	a	.66	1.30	5.45	5.35	2.60	1.74	2.44	2.60	2.66	3.70	2.69	5.70
0.0	b	.29	.40	.68	.99	1.53	1.82	5.78	2.59	4.52	5.30	2.40	2.82
0.0	c	.66	.71	1.50	1.48	2.35	2.92	4.95	2.28	4.70	2.75	2.21	5.70
5.0	13	.36	.29	.71	2.12	1.36	3.35	3.33	2.82	1.95	1.79	1.90	1.88
"	a	.76	1.22	.69	1.38	8.60	9.99	2.65	2.35	1.60	1.32	1.62	5.21

TABLE VII. (CONTINUED) SEDIMENT VANE SHEAR STRENGTHS IN THE TEST PIT

VELOCITY ft/sec	STATION	DEPTH 6"	12"	18"	24"	30"	36"	42"	48"	54"	60"	66"	72"
CONE (CONT)													
5.0	b	1.18	.54	.49	3.11	2.49	1.79	1.72	2.08	1.44	1.31	1.28	1.28
"	c	.95	.67	.82	1.88	3.03	3.15	2.96	1.80	2.57	2.12	1.62	2.10
10.0	30	.22	.15	.31	3.25	7.50	6.30	6.90	4.92	8.70	3.65	3.01	2.49
"	a	.17	.35	.66	2.28	4.78	5.00	8.46	5.80	6.11	5.45	3.27	3.29
"	b	.45	.19	.22	.34	.75	3.45	8.32	9.46	7.64	4.63	2.92	4.93
"	c	.33	.24	.69	2.33	2.19	2.49	4.38	3.81	2.92	3.15	3.67	3.59
15.0	31	.15	.15	.20	.55	1.14	1.68	2.45	1.79	7.26	3.76	5.79	5.35
"	a	.10	.15	.41	1.20	2.26	1.60	1.74	5.43	8.93	9.90	4.47	4.85
"	b	.28	.15	.17	.24	.80	1.32	1.11	2.71	2.40	3.80	3.38	4.01
"	c	.70	.43	.33	1.04	2.89	2.07	4.12	5.91	6.66	5.46	5.92	3.57
20.0	32	.36	.38	.76	1.32	1.60	6.32	5.70	2.60	2.23	2.36	2.54	5.80
"	a	.43	.73	1.03	2.16	2.30	5.35	2.34	3.01	2.64	2.85	3.72	3.80
"	b	.66	1.01	.87	7.20	4.94	2.82	2.17	1.97	2.54	2.80	2.74	4.13
"	c	1.39	.54	1.91	2.36	2.97	3.59	1.60	1.76	3.34	3.45	2.66	3.16
OTHER MEASUREMENTS													
	39	1.57	1.22	1.13	.87	.70	.68	.68	1.57	2.61	2.18	3.27	1.94
	41	.69	.73	.73	1.57	1.58	1.57	5.90	7.65	2.36	2.70	2.65	2.78
	-	.67	.60	.45	.90	1.40	1.56	1.75	1.50	1.25	1.90	1.75	1.60
	18	.20	.45	.85	1.05	1.05	1.45	1.65	1.40	1.25	1.20	1.15	1.30
	a	.40	.65	.65	.75	.85	.85	.75	.90	.90	.20	.35	.60
	b	.60	1.20	.85	.85	1.00	1.00	1.10	1.20	.90	.70	.70	1.00
	c	.80	1.20	1.85	1.70	1.15	1.10	1.15	1.30	1.15	1.00	3.20	1.70
	21	.10	.15	.35	.60	1.00	1.05	1.00	.80	.60	.40	.90	2.50
	a	.30	.70	1.10	1.20	1.00	1.05	1.15	.85	.95	1.30	1.90	2.90
	b	.40	.85	1.20	1.60	2.05	1.50	1.10	.95	1.10	1.30	2.15	2.90
	c	.60	1.05	1.25	1.65	2.25	1.65	1.25	1.20	1.45	1.75	2.60	3.25
	24	.40	1.05	.80	.90	1.05	.80	.80	1.35	1.40	.90	.75	.90
	a	.60	1.40	1.20	1.15	1.20	1.20	1.20	1.50	1.60	1.80	1.35	1.50
	b	1.10	1.75	2.15	2.05	1.35	1.75	1.60	1.60	1.75	2.05	1.95	2.20

TABLE VII. (CONTINUED) SEDIMENT VANE SHEAR STRENGTHS IN THE TEST PIT

TABLE VIII. MEAN SHEAR STRENGTHS AND STANDARD DEVIATIONS OF TEST PIT.

DEPTH (in)	MEAN SHEAR STRENGTHS (psi)		ONE STANDARD DEVIATION (psi)	
6"	$.50_{(55)}$	$.60_{(69)}$	.23	.38
12"	$.73_{(60)}$	$.75_{(73)}$	.32	.44
18"	$.99_{(61)}$	$1.11_{(73)}$	.47	.84
24"	$1.50_{(60)}$	$1.72_{(73)}$	.63	1.21
30"	$1.80_{(60)}$	$2.22_{(73)}$	.62	1.57
36"	$2.03_{(56)}$	$2.77_{(73)}$	.70	1.94
42"	$1.98_{(50)}$	$2.87_{(73)}$	.60	1.87
48"	$2.20_{(57)}$	$2.71_{(72)}$	.74	1.60
54"	$1.93_{(25)}$	$3.40_{(34)}$	.75	1.96
60"	$2.34_{(25)}$	$2.69_{(34)}$	.71	1.81
66"	$2.52_{(28)}$	$2.47_{(34)}$	.82	1.21
72"	$2.52_{(24)}$	$3.04_{(34)}$	.87	1.49

Note: The first columns under the shear strengths and standard deviations are values computed with the anomalous points discarded. The second columns are values computed with all the data points. The subscripts in parenthesis are the number of data points.

water was continually added to the test pit to offset evaporation losses and the top of the pit was continually being reworked by raking. In general, a virgin undisturbed sediment should have a finite strength at the surface.

C. RESULTS

Table IX summarizes the observed penetration depths, the predicted depths, and tabulates the difference between observed and predicted. A numerical analysis of the differences between observed and predicted depths was not made because, with few exceptions, the method developed accurately predicted the penetration depth within the experimental uncertainties of depth measurement and shear strength accuracy. The method overestimated penetration 17 times and underestimated penetration 22 times. The largest differences were underestimates of penetration. In all cases of differences greater than four inches, the prediction had to rely on an adjusted shear strength. This indicated a problem with measuring the shear strength at that station and implied the presence of a soft pocket in the sediment. The large discrepancies also occurred with impact velocities of five feet per second.

Table X sets forth the penetration data along with notes taken from movies of the tests. The time-to-penetrate was observed by counting the frames of the movie film from object impact until all downward motion had ceased. The rebound time was also observed by counting movie frames. The rebound distance was estimated from the pictures and is believed

Table IX. SUMMARY OF RESULTS

OBJECT VELOCITY (ft/sec)	PENETRATION OBSERVED (in)	PENETRATION PREDICTED (in)	DIFFERENCE (in)
SPHERE (wt. = 561 lbs)			
0.0	9.5"	10.7"	+ 1.2"
5.0	13.5"	12.1"	- 1.3"
10.0	14.0"	14.0"	0.0"
15.0	24.2"	24.5"	+ 0.3"
20.0	20.0"	20.5"	+ 0.5"
5.0	16.0"	11.5"	- 4.5"
10.0	16.0"	12.1"	- 3.9"
15.0	19.0"	23.0"	+ 4.0"
20.0	19.5"	20.4"	+ 0.9"
HORIZONTAL CYLINDER (wt. = 540 lbs)			
0.0	5.5"	6.0"	+ 0.5"
5.0	11.5"	7.5"	- 4.0"
10.0	13.0"	13.8"	+ 0.8"
15.0	17.0"	17.0"	0.0"
20.0	16.0"	15.9"	- 0.1"
20.0	14.7"	14.7"	0.0"
CYLINDER ON FLAT END (wt. = 540 lbs)			
5.0	14.0"	8.7"	- 5.3"
10.0	15.5"	12.8"	- 2.7"
15.0	15.0"	14.2"	- 0.8"
20.0	-----	16.2"	-----
0.0	8.0"	8.4"	+ 0.4"
5.0	4.2"	4.4"	+ 0.2"
10.0	18.0"	16.0"	- 2.0"
15.0	14.0"	12.7"	- 1.3"
15.0	18.0"	14.6"	- 3.4"
20.0	19.0"	16.8"	- 2.2"

TABLE IX. (CONTINUED) SUMMARY OF RESULTS

OBJECT VELOCITY (ft/sec)	PENETRATION OBSERVED (in)	PENETRATION PREDICTED (in)	DIFFERENCE (in)
CYLINDER ON FLAT END (wt. = 561 lbs)			
5.0	-----	12.6"	-----
10.0	14.0"	14.0"	0.0"
15.0	18.5"	20.4"	+1.9"
20.0	13.5"	16.1"	+2.6"
CUBE (wt. = 702 lbs)			
0.0	4.5"	3.7"	-0.8"
5.0	5.7"	4.4"	-1.3"
10.0	8.5"	9.7"	+1.2"
15.0	13.0"	12.8"	-0.2"
20.0	17.0"	14.9"	-2.1"
RECTANGLE (parallelopiped, wt. = 1014 lbs)			
0.0	3.0"	3.2"	+0.2"
5.0	5.0"	7.0"	+2.0"
10.0	9.2"	9.4"	+0.2"
15.0	14.8"	14.7"	-0.1"
15.0	15.5"	19.0"	+3.5"
20.0	21.6"	20.1"	-1.5"
CONE (wt. = 1127 lbs)			
0.0	55.0"	50.0"	-5.0"
5.0	53.5"	51.0"	-2.5"
10.0	49.5"	54.0"	+4.5"
15.0	65.0"	64.0"	-1.0"
20.0	62.5"	59.0"	-3.5"

accurate to one inch. Penetration depth refers to the object's final resting position and did not exclude the rebound distance. The percent of ultimate bearing capacity was calculated as; the ultimate bearing capacity of the sediment at the depth the object came to rest, divided by the actual force applied to the sediment by the object at its final resting position. The shear strength adjusted column indicates whether or not an anomalous shear strength value was adjusted which directly affected the calculations of penetration prediction.

The time-to-penetrate measurement was done in an inexact manner, but is remarkably constant when the range of velocities and different object shapes are considered. Its relative constancy in relation to the other parameters may indicate that it is related to a unique basic property of the sediment. Schmid [1966] observed the same phenomena when testing small penetrometers with different impact velocities.

The rebound time and distance were very difficult to estimate due to the short duration and fact that splatter sometimes partially obscured the object. Some of the rebound of the object, and apparent elastic behavior of the sediment was originally thought to be caused by a buoyancy effect. However the cavity formed by penetration did not collapse until rebound was over and the object was essentially at rest. Subjectively it appears that rebound is a function of an elastic property of the sediment.

The percent of ultimate bearing capacity that was reached by the different objects seems to relate to impact velocity. In all the penetration tests the objects were left in place for at least 24 hours and in some cases up to eight days and then checked to see if they had settled further into the sediment. No further settlement was observed in any case. At an impact velocity of five feet-per-second the objects consistantly penetrated to a level where 300 percent of the ultimate bearing capacity was available to support the object. This implies that a structure being emplaced by a free-fall technique would only require a velocity of five feet-per-second to generate the safety factor of three recommended in soil mechanics in a situation where the ultimate bearing capacity equation is used.

As observed in the movies, any air entrapped under the object had negligible effect on either rebound or penetration depth. Rounded objects such as the sphere and horizontal cylinder did not behave differently from the flat sided objects that did entrap some air.

Cratering and pile up of the sediment was slight. In all cases, even with the rectangular parallelepiped impacting at 20 feet per second, the crater lip was less than 2 inches high. The sediment moved laterally away from the objects and not up.

Table X. NOTES FROM PENETRATION TESTS

SPHERE

OBJECT VELOCITY (ft/sec)	PREDICTED PENETRATION (in)	DIFFERENCE FROM OBSERVED (in)	DAY OF TESTS SEPT. 1965	TIME TO PENETRATE (sec)	REBOUND DISTANCE (in)	TIME FOR REBOUND (sec)	PERCENT ULTIMATE BEARING CAPACITY	SHEAR STRENGTH ADJUSTED	NOTES FROM MOVIES OF THE TESTS
0.0	10.7	+1.2	15	.25	½	.13	240	no	----
5.0	12.2	-1.3	15	.25	1	.13	325	no	The sediment moved with a horizontal motion five feet from the drop position.
10.0	14.0	0.0	15	.22	1	.16	493	no	The sphere rotated during and after rebound.
15.0	24.5	+0.3	15	.22	1	.19	478	yes	A neat crater with a small lip was formed around the sphere. The sediment moved horizontally away from the sphere.
20.0	20.5	+0.5	15	.17	2	.19	795	no	The sediment was observed to move horizontally away and up slightly during penetration. It moved toward the sphere as the sphere came to rest.
5.0	11.5	-4.5	13	.28	½	.10	336	yes	The shear strength at six inches was not recorded. The sphere went straight in forming a small crater.
10.0	12.1	-3.9	13	.22	½	.12	590	no	-----
15.0	23.0	+4.0	13	.22	1	.10	670	yes	The shear strength at six inches was not recorded. A small crater was formed with the sediment having a peeled back appearance at the rim.
20.0	20.4	-0.9	13	.18	2½	.12	1060	yes	The shear strength at six inches was not recorded. The crater slumped in after the sphere came to rest.

TABLE X. (CONTINUED)

OBJECT VELOCITY (ft/sec)	PREDICTED PENETRATION (in)	DIFFERENCE FROM OBSERVED (in)	DAY OF TESTS SEPT, 1965	TIME TO PENETRATE (sec)	REBOUND DISTANCE (in)	TIME FOR REBOUND (sec)	PERCENT ULTIMATE BEARING CAPACITY	SHEAR STRENGTH ADJUSTED	HORIZONTAL CYLINDER NOTES FROM MOVIES OF THE TESTS
0.0	6.0	+0.5	14	.22	0	-	206	no	The cylinder went straight in with little splatter and rotated about its axis after maximum penetration.
5.0	7.5	-4.0	14	.22	1	.10	317	yes	The cylinder went straight in but only one end rebounded. At rest one end was three inches lower than the other.
10.0	13.8	+0.8	14	.22	2½	.22	495	no	The cylinder went straight in and rebounded straight up with a small amount of splatter. Four feet away from the cylinder the sediment moved horizontally.
15.0	17.0	0.0	14	.22	4	.25	607	no	The cylinder went straight in but one end penetrated four inches more than the other. The rebound was at an angle. A definite horizontal motion of the sediment was observed up to six feet away from the cylinder.
20.0	15.9	-0.1	14	.22	-	.19	848	no	One end penetrated seven inches more than the other. Not much splatter was observed. A crater was made but it slid in around the cylinder during rebound.
20.0	14.7	0.0	14	.19	3	.22	1020	yes	Cylinder went straight in and rebounded straight up.
									In all the tests the cylinder rotated and wobbled at the maximum penetration depth as if it was floating in a liquid.

OBJECT VELOCITY (ft/sec)	PREDICTED PENETRATION (in)	DIFFERENCE FROM OBSERVED (in)	DAY OF TESTS SEPT, 1965	TIME TO PENETRATE (sec)	REBOUND D DISTANCE (in)	TIME FOR REBOUND (sec)	PERCENT ULTIMATE BEARING CAPACITY	SHEAR STRENGTH ADJUSTED	TABLE X. (CONTINUED) CYLINDER ON FLAT END (wt. -540 lbs) NOTES FROM MOVIES OF THE TESTS
5.0	8.7	-5.3	10	---	-	---	268	yes	Only before and after pictures were available. The shear strength at six inches was not recorded.
10.0	12.8	-2.7	10	---	-	---	348	no	Only before and after pictures were available.
15.0	14.2	-0.8	10	.19	1	.12	580	no	Cylinder went straight in and rebounded straight up.
20.0	16.2	----	10	.22	1	.12	750	yes	The cylinder was swinging when it was dropped and was canted about six degrees on impact. It continued to tip completely over as it penetrated and came to rest in an almost horizontal position with a little over one half its volume submerged. It was impossible to estimate a penetration depth.
0.0	8.4	+0.4	15	.25	-	---	168	no	The movies showed three different trials at zero velocity. In each case the cylinder tipped over after reaching its maximum penetration depth. The observed penetration was estimated from the movies to be eight inches in all three cases.
5.0	4.4	-0.2	15	.19	½	.12	319	no	----
10.0	16.0	-2.0	15	.22	-	.19	369	no	The cylinder went straight in to about 14 inches then tipped on rebound. One side penetrated to 22 inches and the other to 14 inches.

TABLE X. (CONTINUED)

OBJECT VELOCITY (ft/sec)	PREDICTED PENETRATION (in)	DIFFERENCE FROM OBSERVED (in)	DAY OF TESTS SEPT. 1965	TIME TO PENETRATE (sec)	REBOUND DISTANCE (in)	TIME FOR REBOUND (sec)	PERCENT ULTIMATE BEARING CAPACITY	SHEAR STRENGTH ADJUSTED	CYLINDER ON FLAT END (wt. 540 lbs) NOTES FROM MOVIES OF THE TESTS
15.0	12.7	-1.3	15	.19	1	.12	583	yes	The cylinder went straight in to about 14 inches then tipped on rebound. One side penetrated to 23 inches and the other to 11 inches. Penetration distance was estimated as 14 inches.
15.0	14.6	-3.4	15	.22	-	.19	534	yes	----
20.0	16.8	-2.2	15	.19	1½	.16	596	yes	Cylinder went straight in and tilted on rebound. In the final resting position one side penetrated to 23 inches and the other to 18.
									CYLINDER ON FLAT END (wt. 561 lbs)
5.0	12.6	----	20	.22	-	---	206	no	The movies showed two trials. In both cases the cylinder tipped completely over making it impossible to record an accurate penetration depth.
10.0	14.0	0.0	20	.22	-	---	475	no	Cylinder went straight in and tilted on rebound.
15.0	20.4	+1.9	20	.22	-	---	443	no	Cylinder went straight in forming a small crater. There was about one inch between the cylinder and the wall of the crater which was filled with the liquid splatter.
20.0	16.1	+2.6	20	.19	-	.10	735	yes	----

TABLE X. (CONTINUED)

CUBE

NOTES FROM MOVIES OF THE TESTS

OBJECT VELOCITY (ft/sec)	PREDICTED PENETRATION (in)	DIFFERENCE FROM OBSERVED (in)	DAY OF TESTS SEPT. 1965	TIME TO PENETRATE (sec)	REBOUND DISTANCE (in)	TIME FOR REBOUND (sec)	PERCENT ULTIMATE BEARING CAPACITY	SHEAR STRENGTH ADJUSTED	NOTES FROM MOVIES OF THE TESTS
0.0	3.7	-0.8	13	.22	-	---	157	yes	The shear strengths were not recorded for this test, therefore a shear strength profile similar to the mean for the mud pit was used. It was biased toward the other profiles determined on the 13 September. Air was trapped underneath the cube and it continued to jet out for about one second after the cube came to rest.
5.0	4.4	-1.3	13	.22	1	.06	332	yes	The cube went straight in and rebounded straight up. There was no entrapped air.
10.0	9.7	+1.2	13	.22	½	.06	412	yes	----
15.0	12.8	-0.2	13	.22	2	.12	507	no	The cube entered the sediment at a slight angle. One side penetrated five inches below the other. Entrapped air vented as the maximum depth was reached. The cube slid about two inches horizontally during the penetration.
20.0	14.9	-2.1	13	.22	-	.12	638	yes	The cube penetrated straight in and rebounded straight up but canted about two inches after resting. A crater was formed with the sediment raised slightly above the mean surface of the mud pit. The rise was visible three feet from the cube.

TABLE X. (CONTINUED)

OBJECT VELOCITY (ft/sec)	PREDICTED PENETRATION (in)	DIFFERENCE FROM OBSERVED (in)	DAY OF TESTS SEPT 1965	TIME TO PENETRATE (sec)	REBOUND DISTANCE (in)	TIME FOR REBOUND (sec)	PERCENT ULTIMATE BEARING CAPACITY	SHEAR STRENGTH ADJUSTED	RECTANGLE NOTES FROM MOVIES OF THE TESTS
0.0	3.2	+0.2	14	.22	-	0.0	154	yes	The rectangle tilted about one inch and slid sideways about two inches during penetration.
5.0	7.0	+2.0	14	.22	½	.12	366	no	----
10.0	9.4	+0.2	14	.22	½	.19	405	yes	The rectangle penetrated straight in until one half the total depth was reached then it tilted with one corner coming to rest three inches below the opposite corner. The sediment formed a crater as usual and moved horizontally away from the rectangle during the penetration.
15.0	14.7	-0.1	14	.22	1	.19	512	no	The rectangle entered straight then at a penetration depth of about eight inches one side dipped about six inches. The rebound further tilted the rectangle and at rest one corner was nine inches lower than the opposite corner.
15.0	19.0	+3.5	14	.25	1½	.16	332	yes	The rectangle penetrated straight in and rebounded straight up. The sediment moved horizontally ten feet distant from the rectangle as it penetrated.
20.0	20.1	-1.5	14	.22	-	.22	708	yes	At a distance of eight feet the sediment moved up then away from the rectangle. The volume of splatter from the impact was estimated to be less than ten percent of the crater volume.

TABLE X. (CONTINUED)

CONE

OBJECT VELOCITY (ft/sec)	PREDICTED PENETRATION (in)	DIFFERENCE FROM OBSERVED (in)	DAY OF TESTS SEPT. 1965	TIME TO PENETRATE (sec)	REBOUND DISTANCE (in)	TIME FOR REBOUND (sec)	PERCENT ULTIMATE BEARING CAPACITY	SHEAR STRENGTH ADJUSTED	
0.0	50.0	-5.0	23	---	-	---	372	yes	The shear strength profile is the average of four sets of data from the location where the cones were dropped. No motion pictures were available for the cone tests.
5.0	51.0	-2.5	23	---	-	---	490	yes	"
10.0	54.0	+4.5	24	---	-	---	645	yes	"
15.0	64.0	-1.0	24	---	-	---	746	yes	"
20.0	59.0	-3.5	24	---	-	---	801	yes	"

IV. CONCLUSIONS AND RECOMMENDATIONS

A rational, phenomenological, theory has been applied to the problems of free-fall penetration into a simulated deep-sea sediment. The theory correlated well with full scale tests. A more complete solution will probably only be available after more is understood about the mechanical properties and dynamic behavior of deep-sea sediment.

A. CONCLUSIONS

The method predicts the penetration of free-falling objects into weak, saturated sediments for an air-to-sediment case within the accuracy of the present state-of-the-art techniques for measuring the sediment mechanical properties. It should work equally well in a water-to-sediment case with some modifications.

The impact duration time, from the instant of contact until the object comes to rest, was observed to be relatively constant and may be a unique property of the dynamic behavior of a sediment type. The duration time was relatively constant even though the penetration distance changed, the object shapes were different, and the kinetic energy of the falling objects ranged from 0 to 5,000 foot-pounds.

The method may be used with larger, heavier objects but caution must be used in extending the method for use with smaller objects since viscous drag and surface adhesion effects may be important for smaller masses.

At high impact velocities the effects of added mass and form drag cannot be neglected in computing penetration depth. The accuracy of the constants and variables in the standard bearing capacity equation have the most control over predicted penetration depths.

B. RECOMMENDATIONS

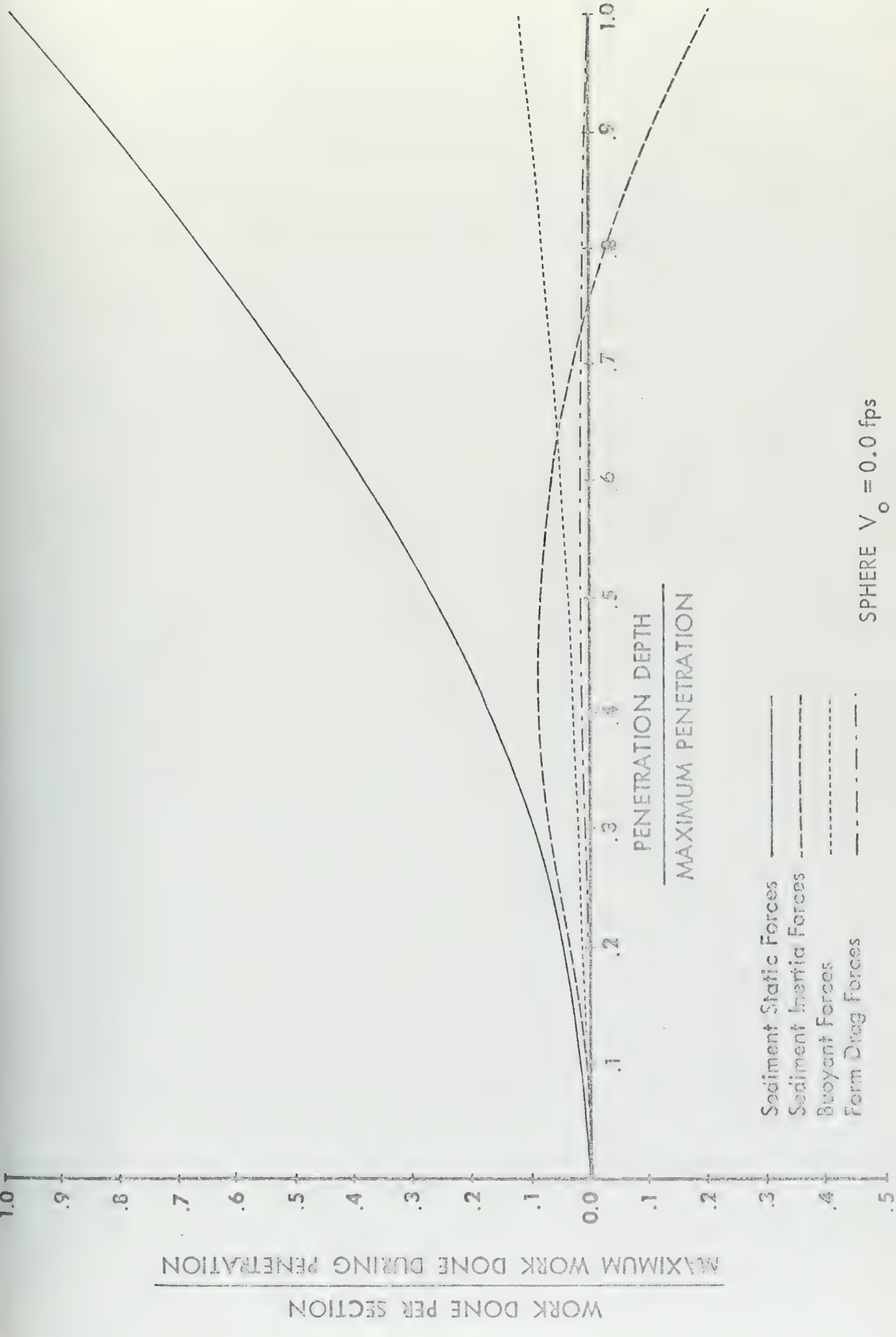
The method should be experimentally verified by full scale tests at sea or by controlled tests in a large tank ashore using a uniform sediment whose mechanical properties are known. Experiments of the scale needed would require a major effort but could include investigations into other unknown areas such as the free-fall attitude and stability of various shapes in water, the verification of terminal velocities of free-falling unstabilized objects in a water column and the study of breakout forces and salvage methods required to retrieve the objects.

Whenever an object is recovered from the deep-ocean floor every effort should be made to obtain photographs of the object. The sediment around the object should be extensively sampled and completely analyzed to allow verification of this method of predicting penetration depth.

APPENDIX A

FORCES ON OBJECTS PENETRATING A TYPICAL SEDIMENT

Appendix A includes a set of curves which qualitatively illustrate the relative influence of each force in the penetration equation. They were obtained by using the sediment shear strength profile typical of the world's deep-ocean basins as determined by Hoag [1970] and shown in Figure 13. The curves are normalized for depth of penetration on the abcissa and the maximum force encountered on the ordinate. Time is independent of the calculations and the shape of the curve near the origin is largely a function of the iteration interval.


WORK DONE PER SECTION
MAXIMUM WORK DONE DURING PENETRATION
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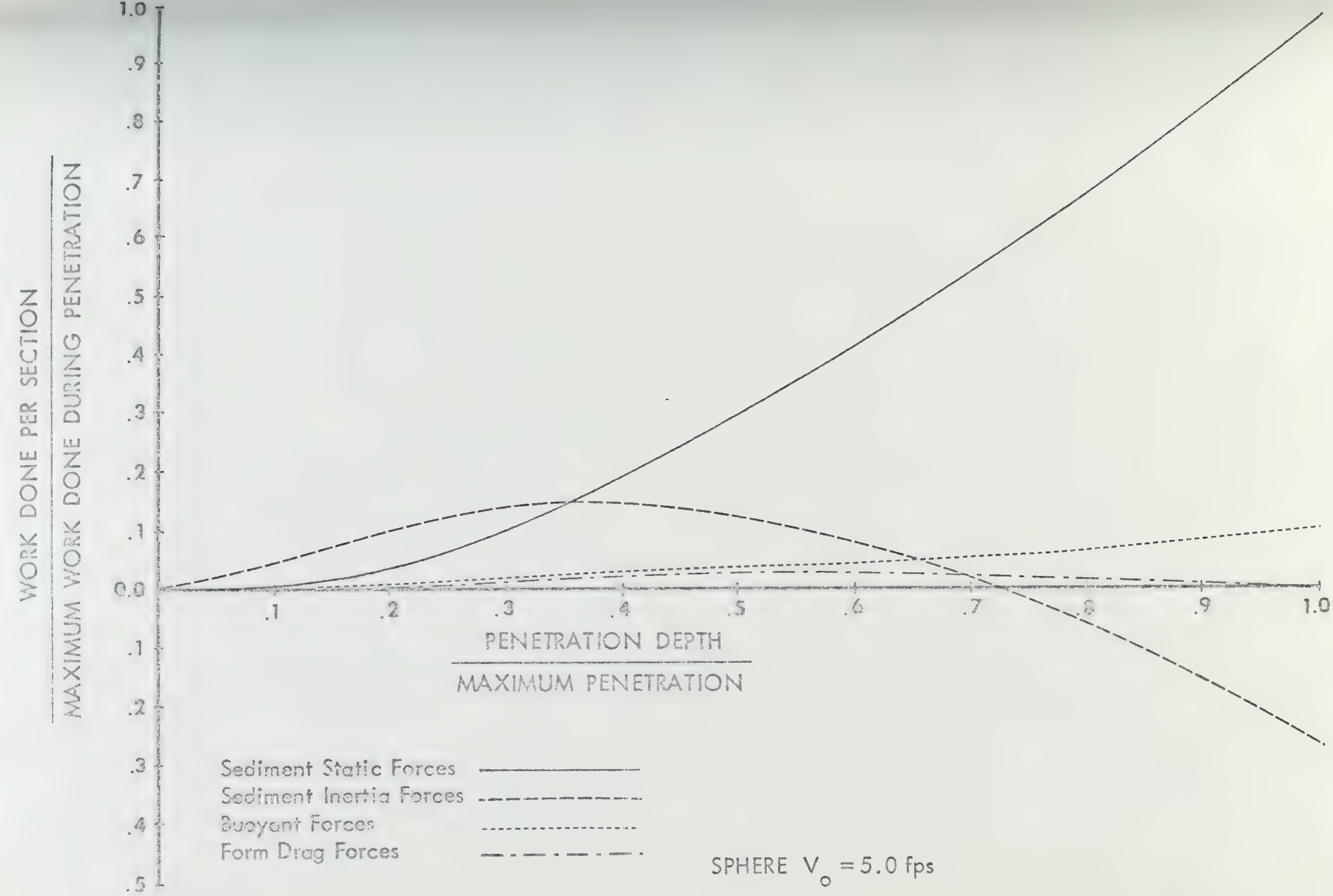
PENETRATION DEPTH
MAXIMUM PENETRATION
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
SPHERE $V_o = 0.0$ fps


WORK DONE PER SECTION
MAXIMUM WORK DONE DURING PENETRATION
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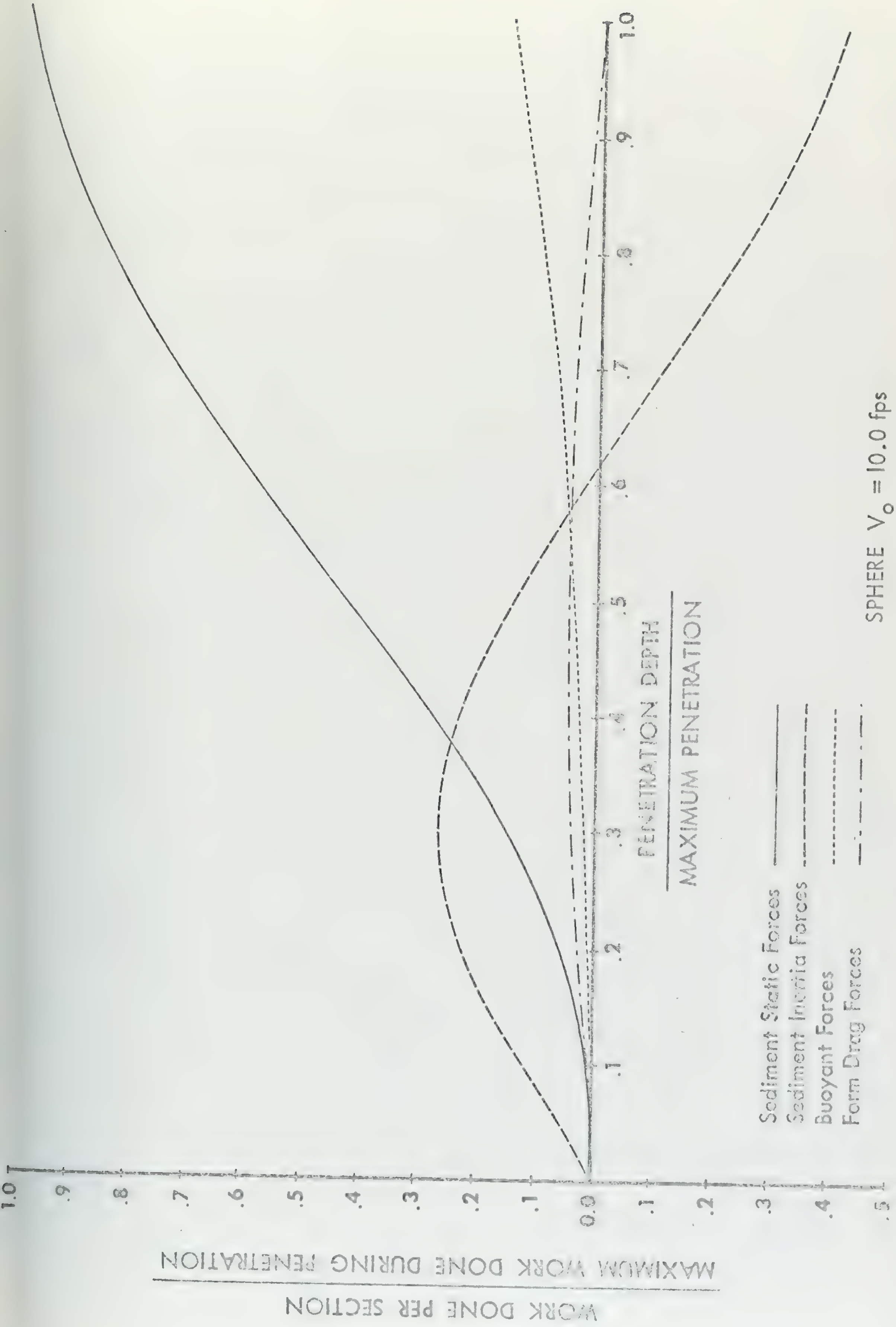
PENETRATION DEPTH
MAXIMUM PENETRATION
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
SPHERE $V_o = 5.0$ fps

WORK DONE PER SECTION
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PENETRATION DEPTH
MAXIMUM PENETRATION
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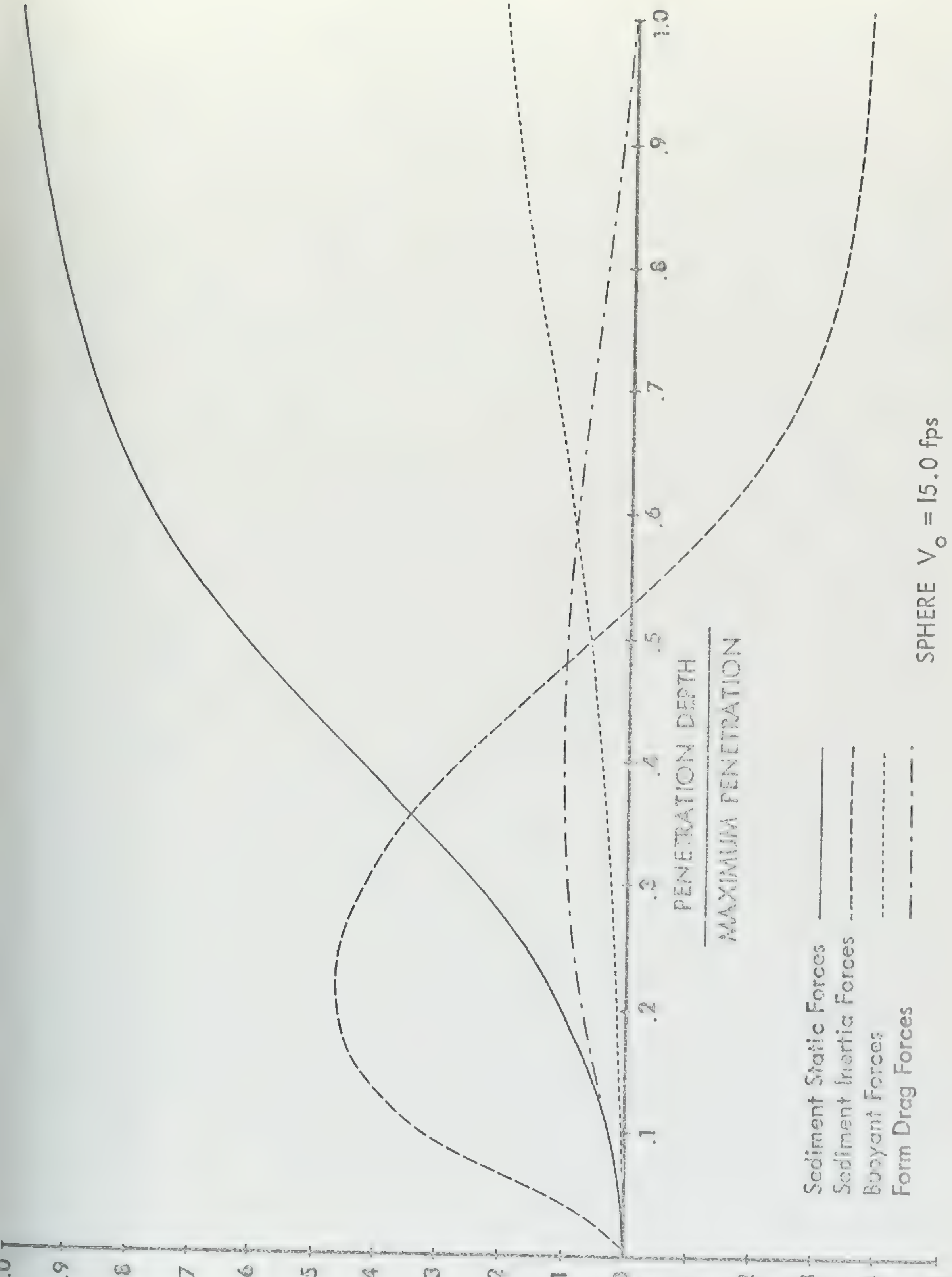
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
SPHERE $V_o = 10.0$ fps


SPHERE $V_o = 15.0$ fps
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
PENETRATION DEPTH / MAXIMUM PENETRATION
WORK DONE PER SECTION / MAXIMUM WORK DONE DURING PENETRATION
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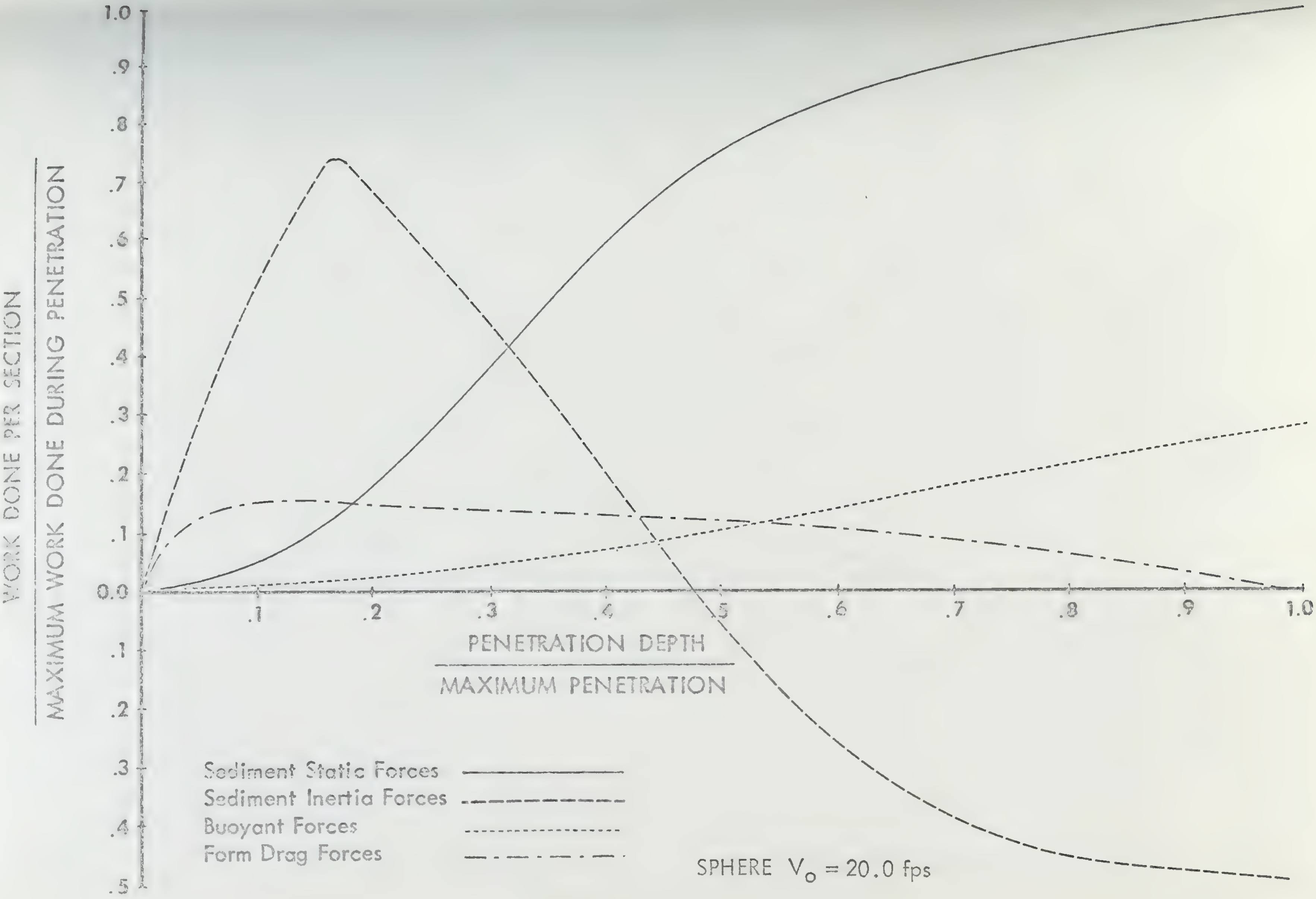
WORK DONE PER SECTION
MAXIMUM WORK DONE DURING PENETRATION
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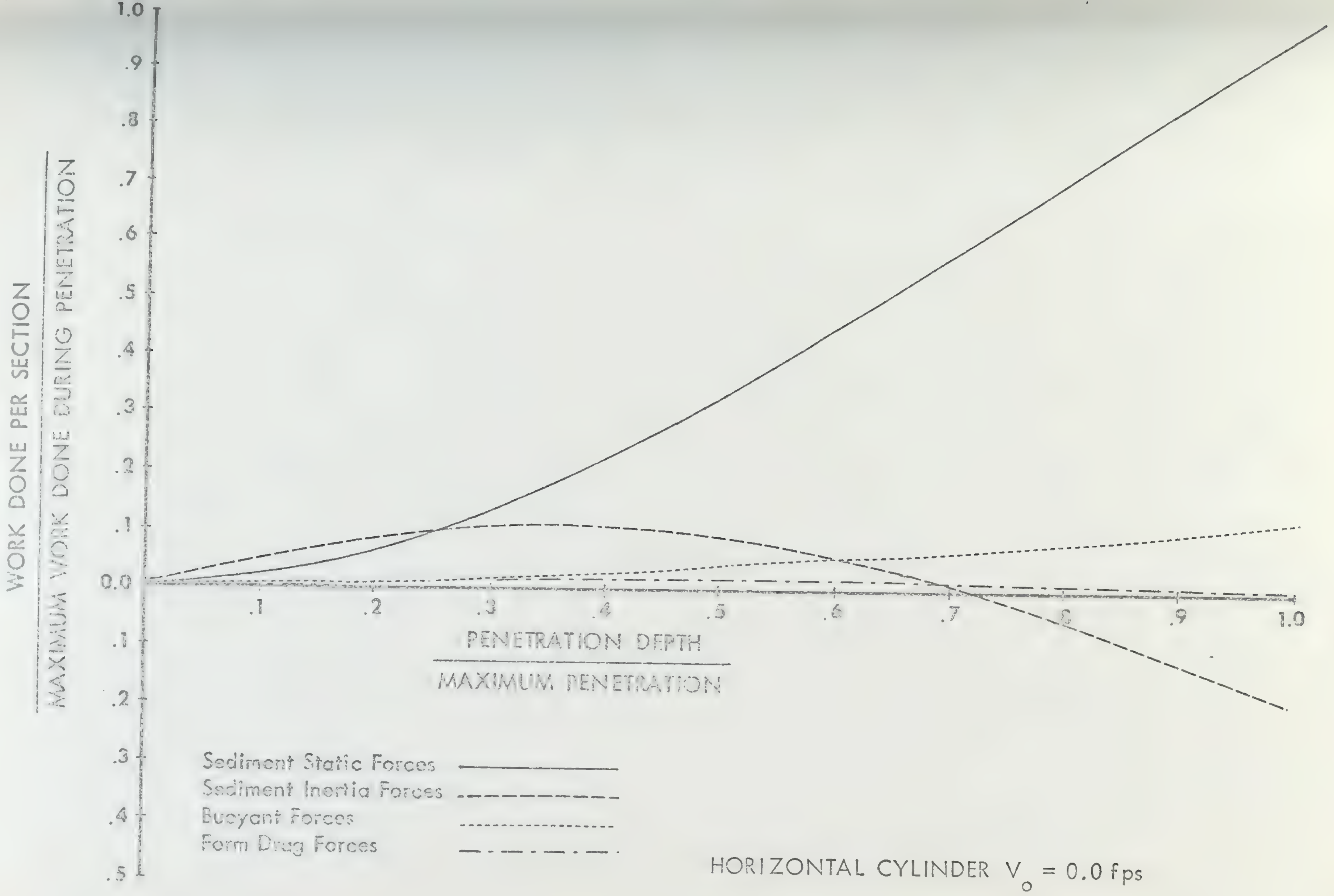
PENETRATION DEPTH
MAXIMUM PENETRATION
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
SPHERE V₀ = 20.0 fps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WORK DONE PER SECTION
MAXIMUM WORK DONE DURING PENETRATION
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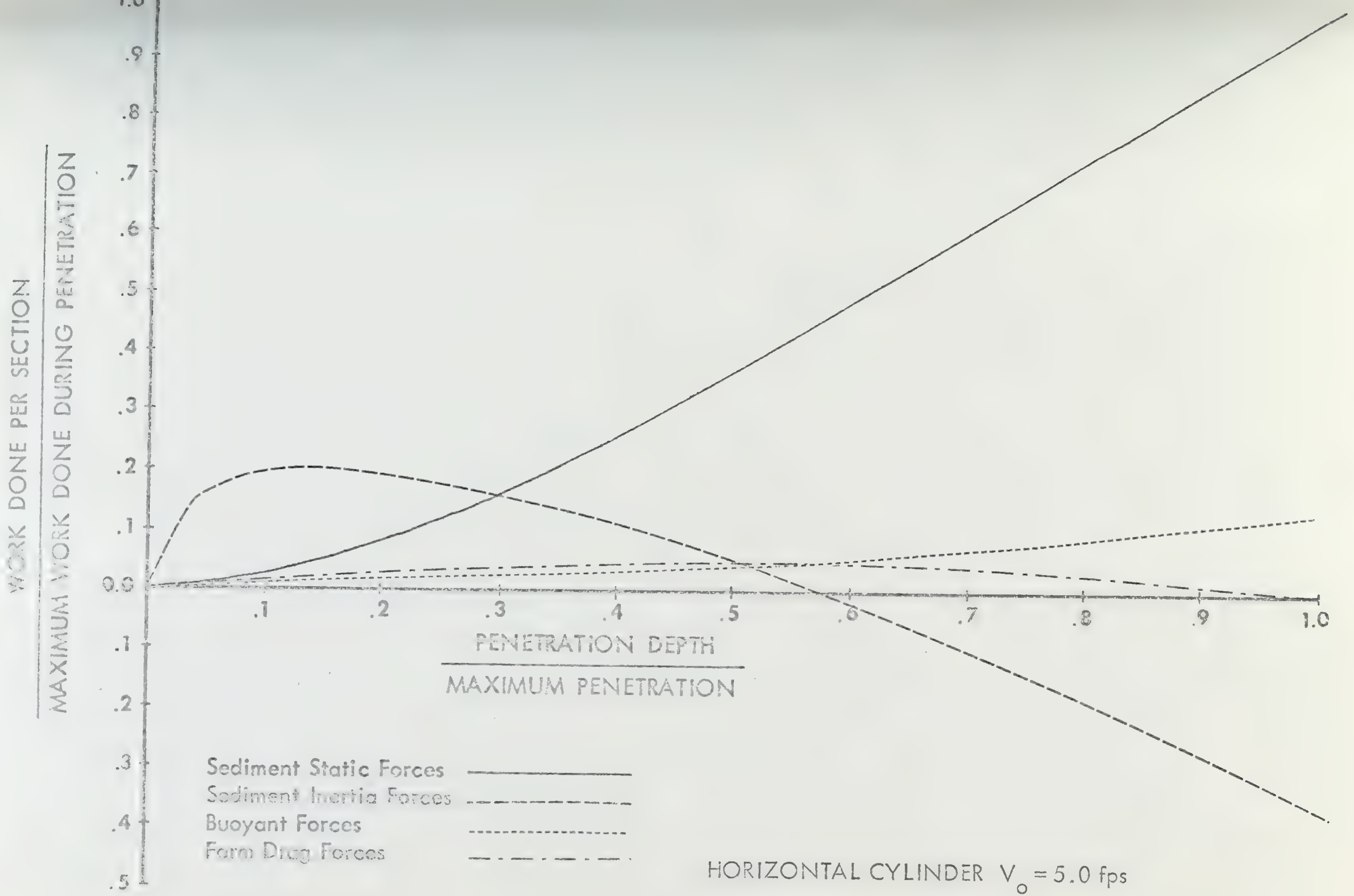
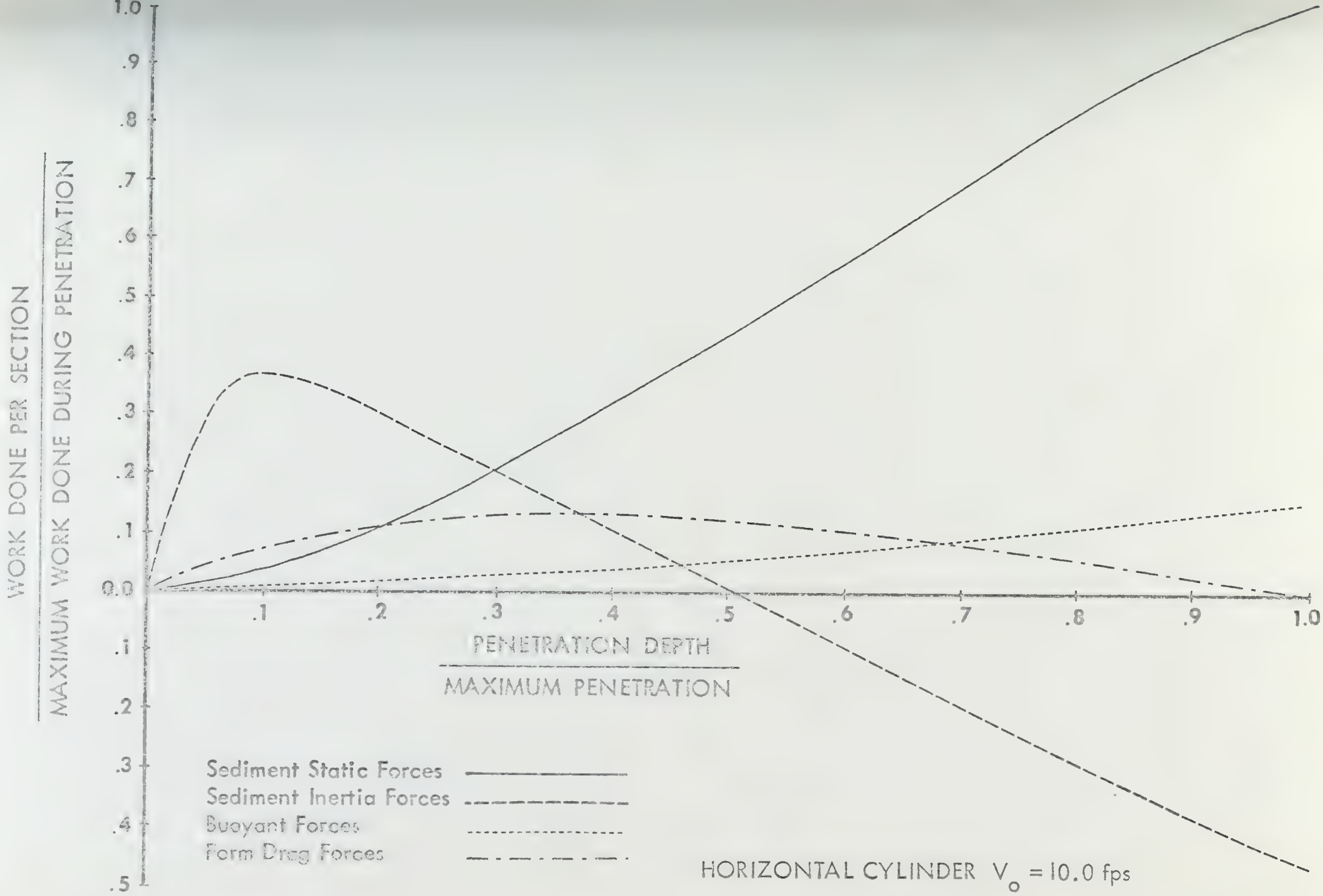
PENETRATION DEPTH
MAXIMUM PENETRATION
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
HORIZONTAL CYLINDER $V_o = 0.0$ fps



HORIZONTAL CYLINDER $V_o = 5.0$ fps


WORK DONE PER SECTION
MAXIMUM WORK DONE DURING PENETRATION
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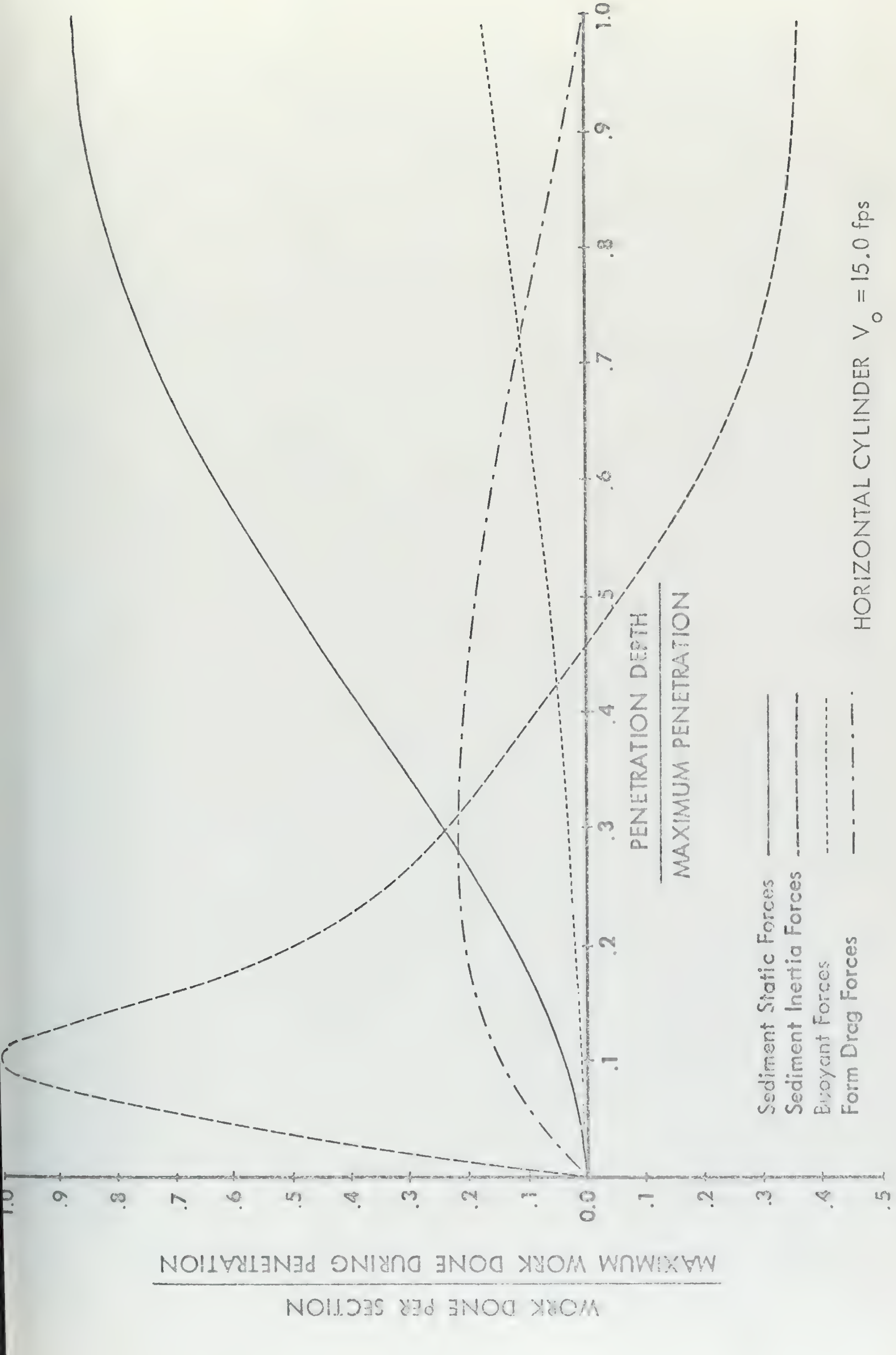
PENETRATION DEPTH
MAXIMUM PENETRATION
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
HORIZONTAL CYLINDER $V_o = 10.0$ fps


WORK DONE PER SECTION
MAXIMUM WORK DONE DURING PENETRATION
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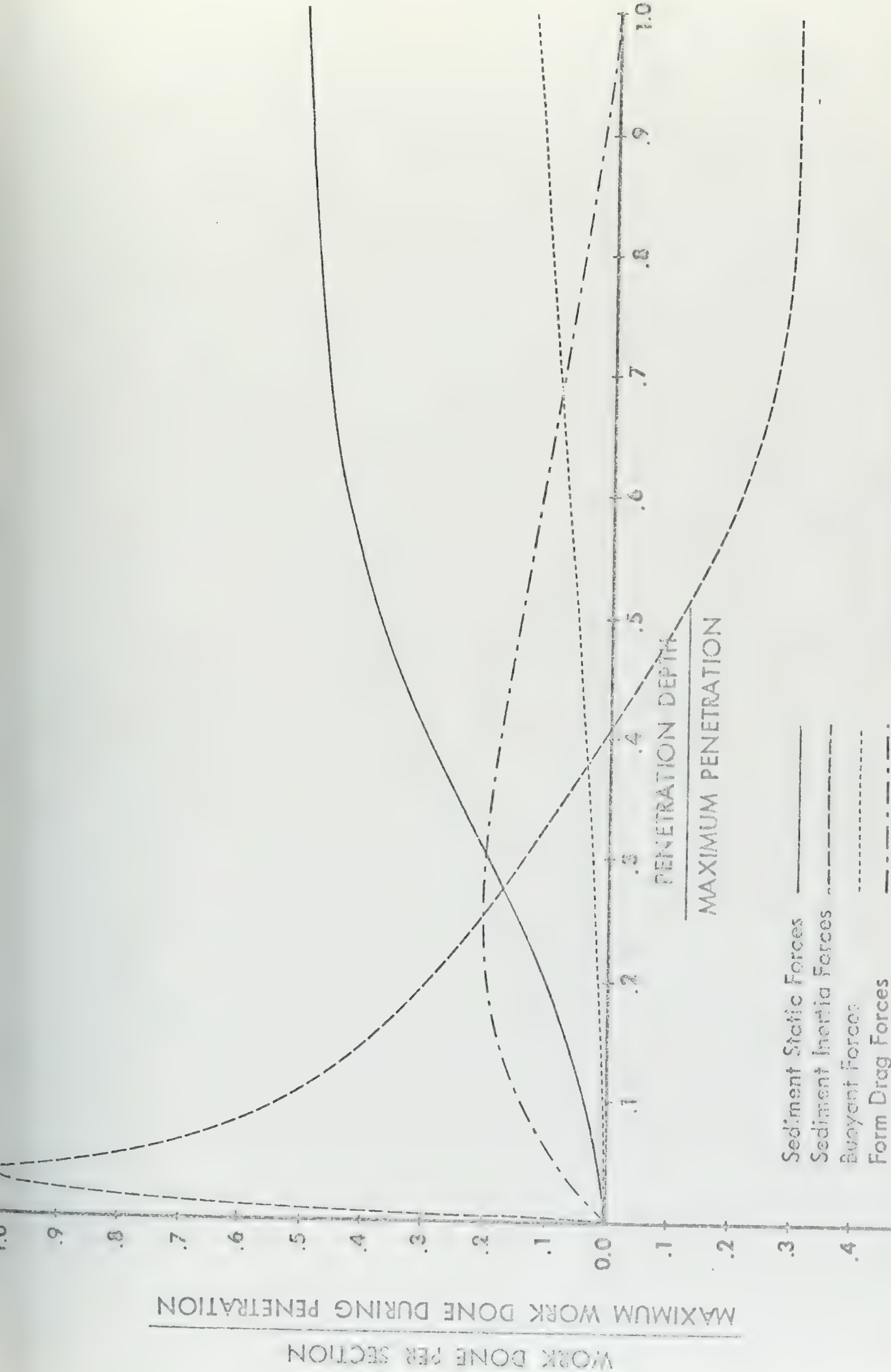
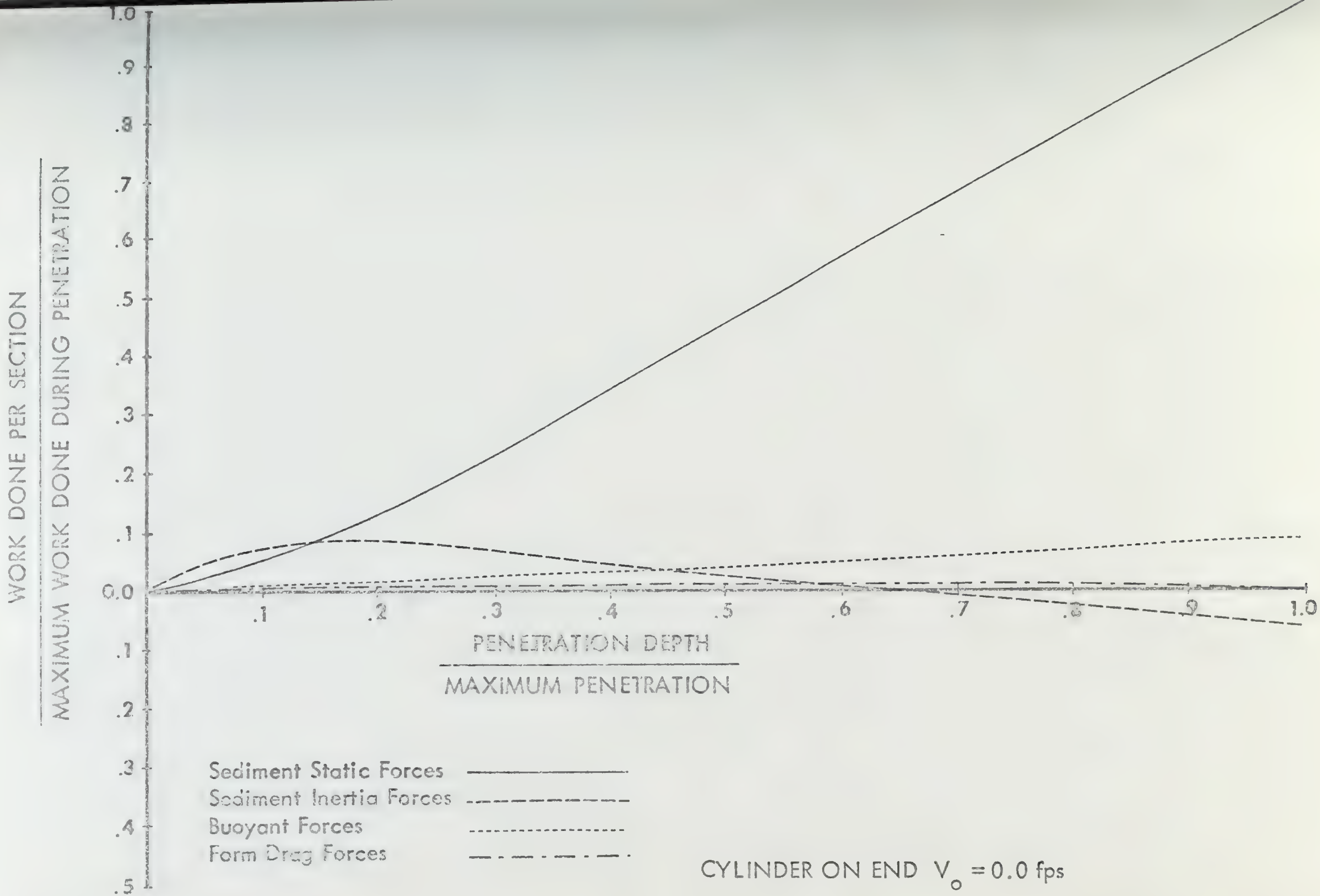
PENETRATION DEPTH
MAXIMUM PENETRATION
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
HORIZONTAL CYLINDER $V_o = 15.0$ fps



HORIZONTAL CYLINDER $V_o = 20.0$ fps


WORK DONE PER SECTION / MAXIMUM WORK DONE DURING PENETRATION
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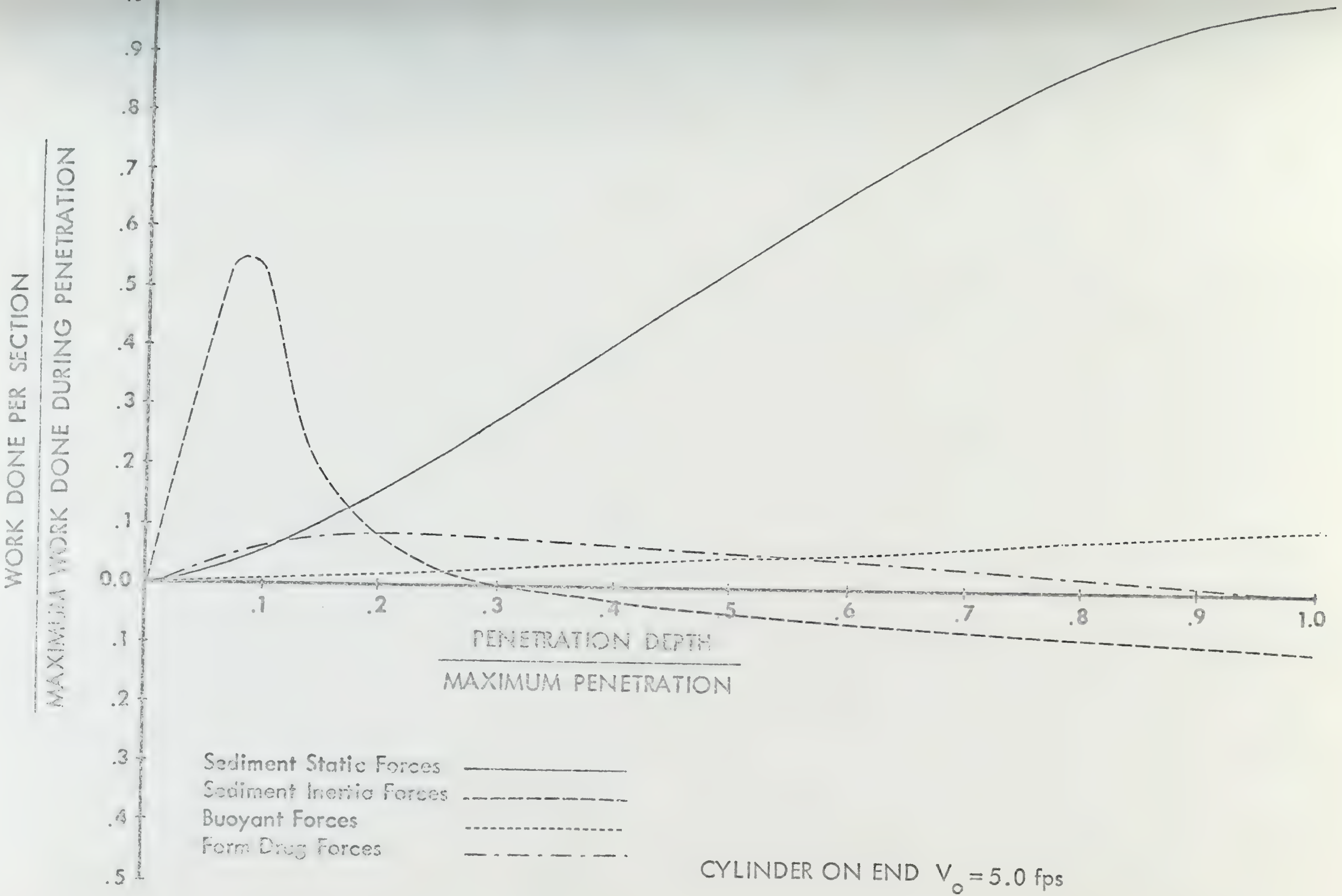
PENETRATION DEPTH / MAXIMUM PENETRATION
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
CYLINDER ON END $V_o = 0.0$ fps



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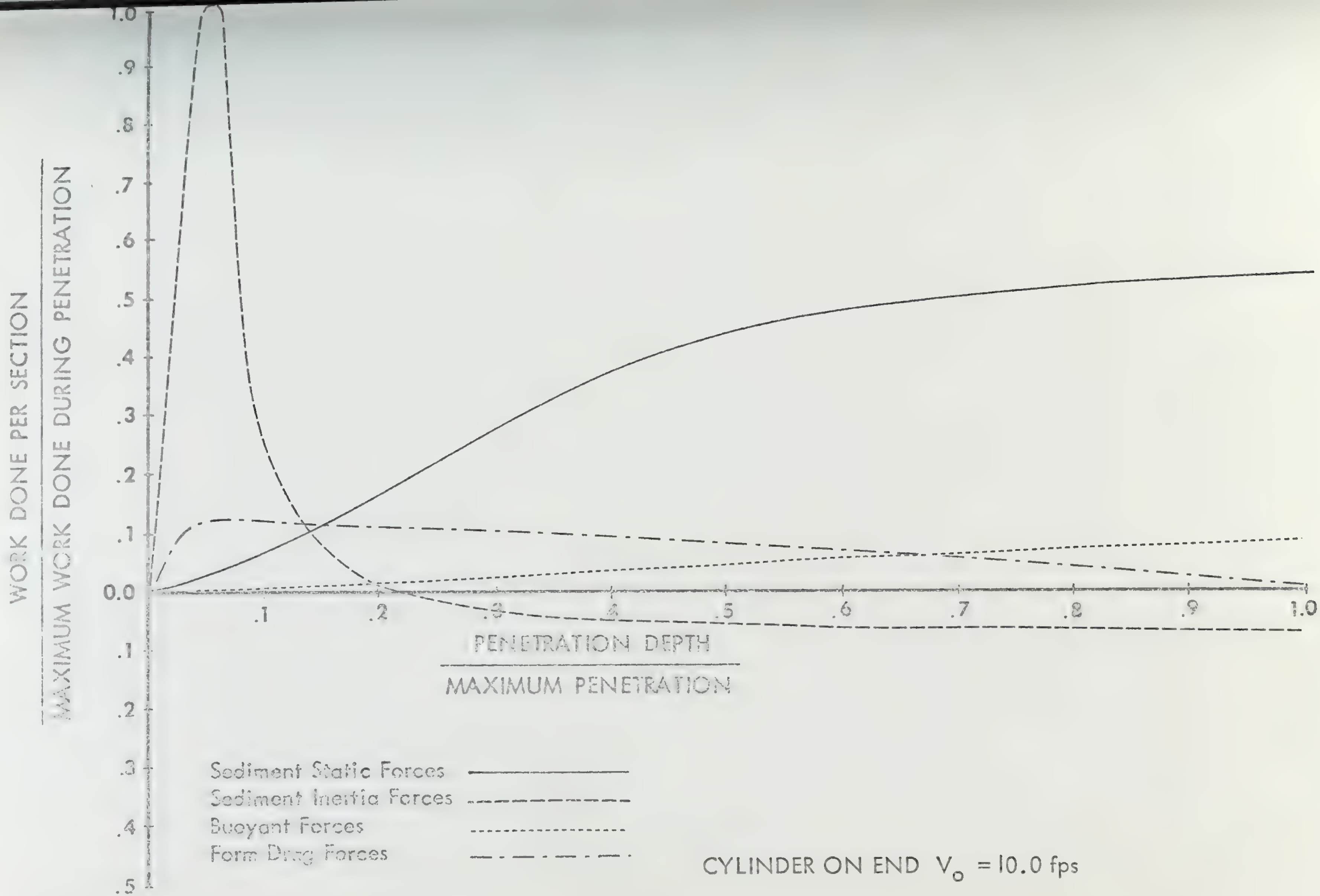

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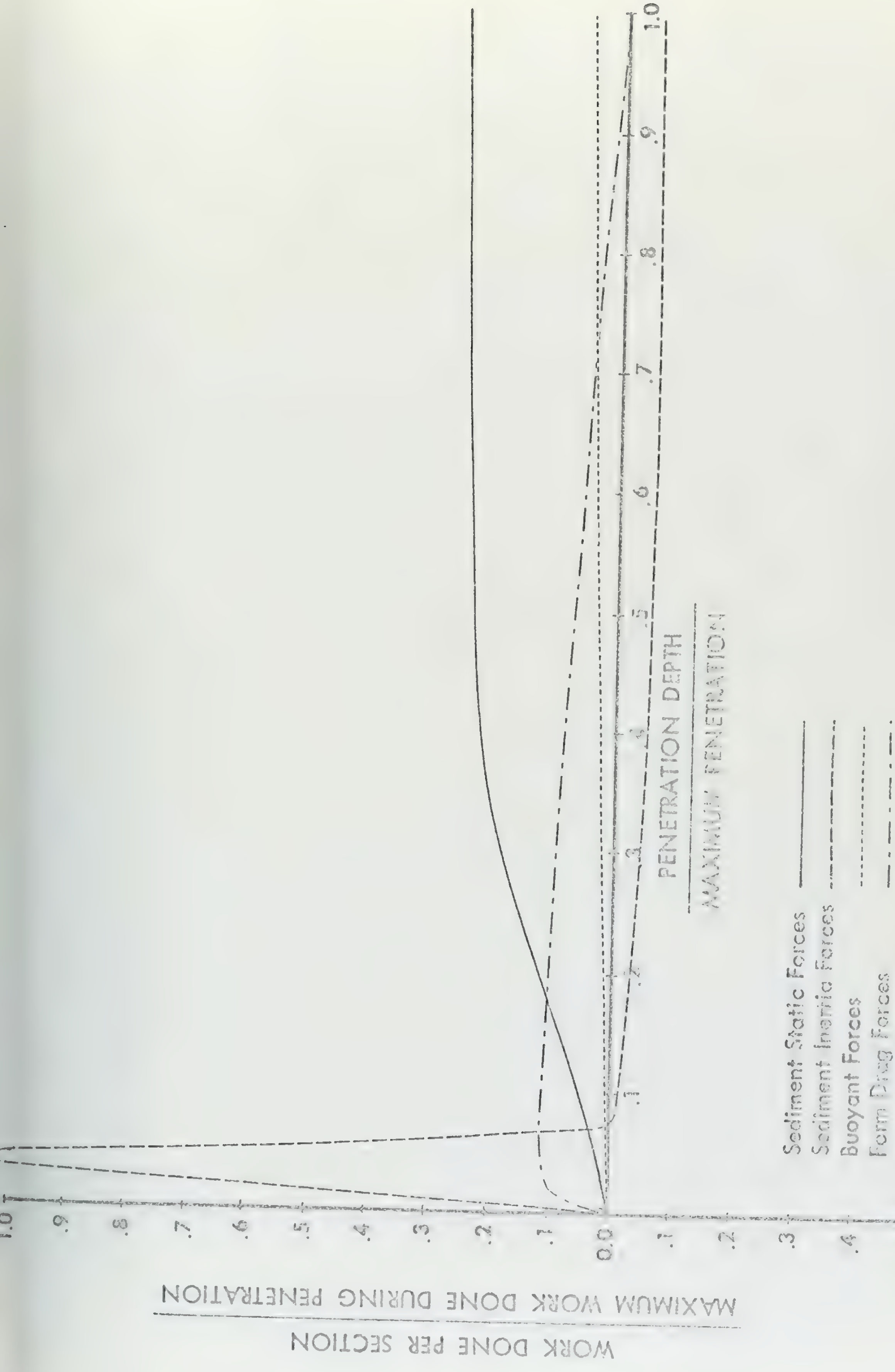
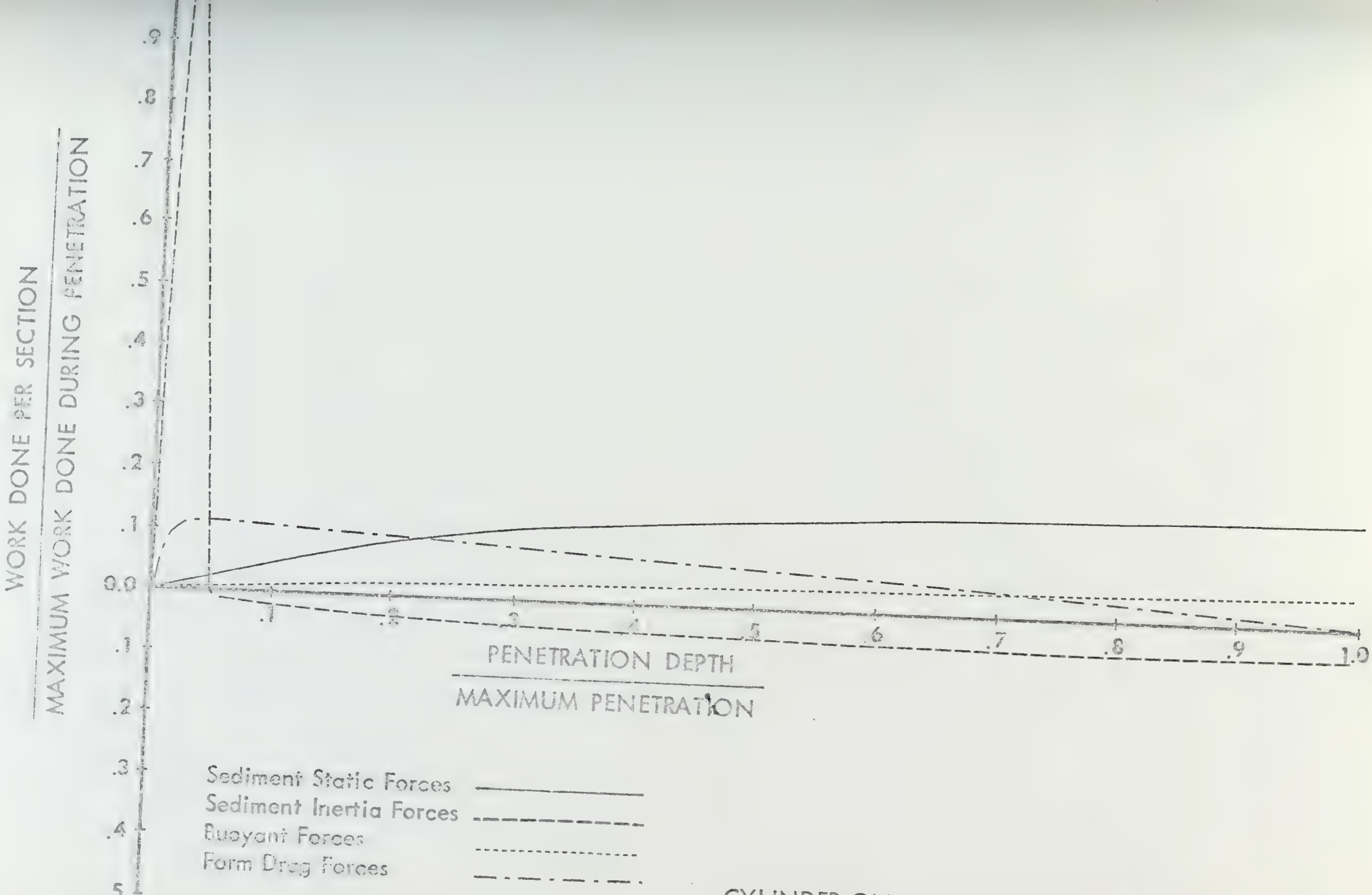
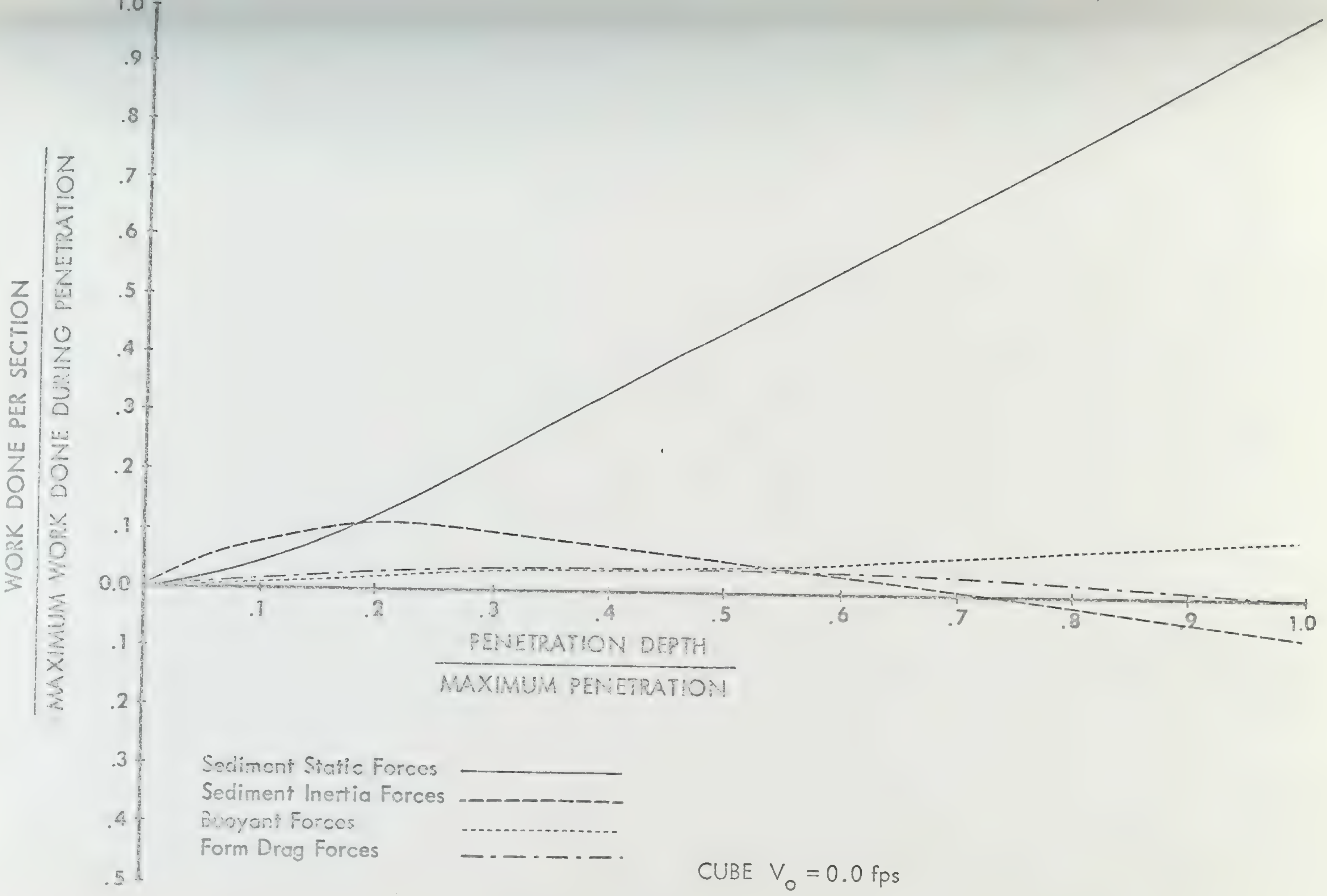


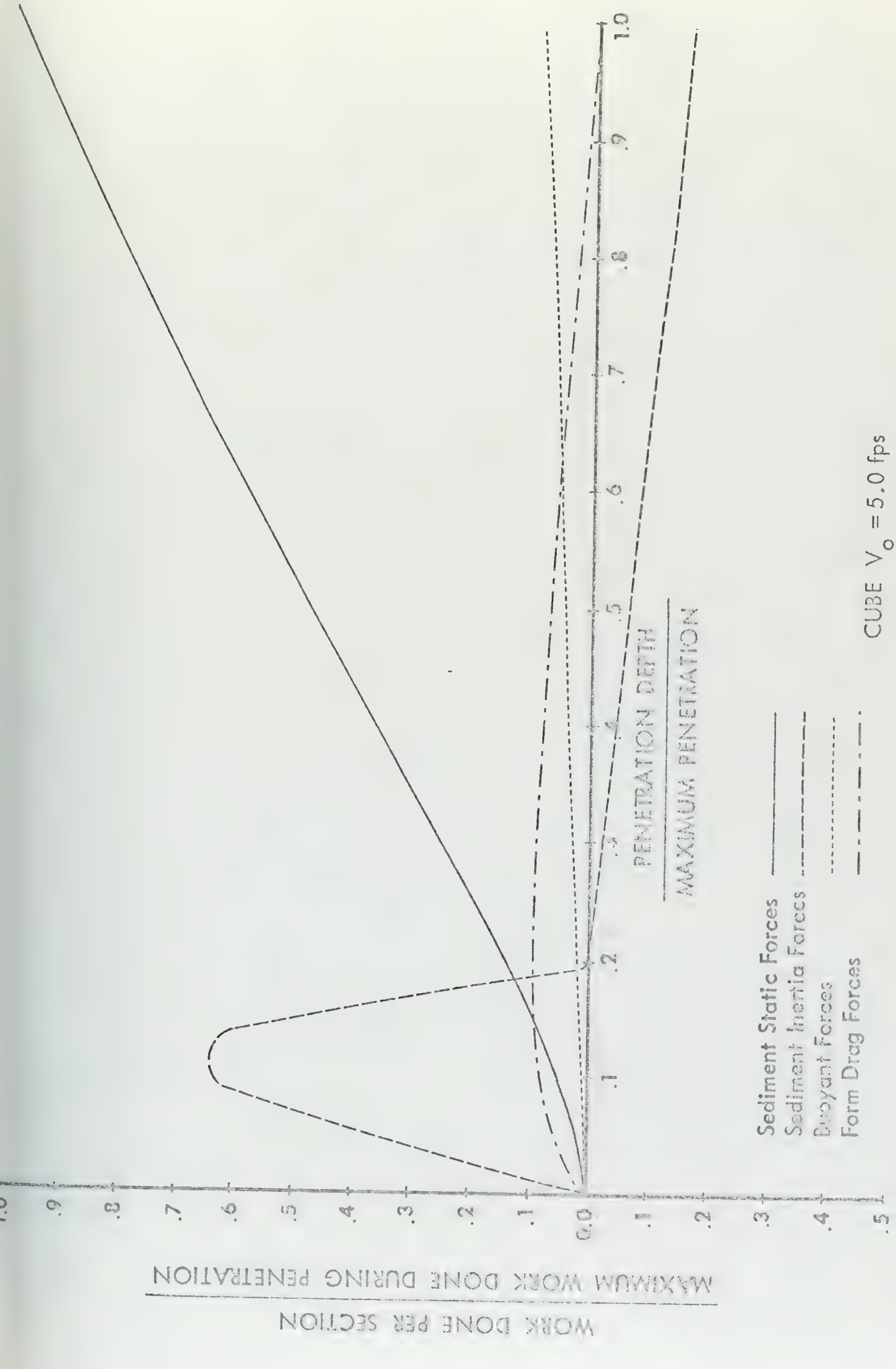
CYLINDER ON END V_o = 15.0 fps



CYLINDER ON END $V_o = 20.0$ fps



CUBE $V_o = 0.0$ fps



WORK DONE PER SECTION
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PENETRATION DEPTH
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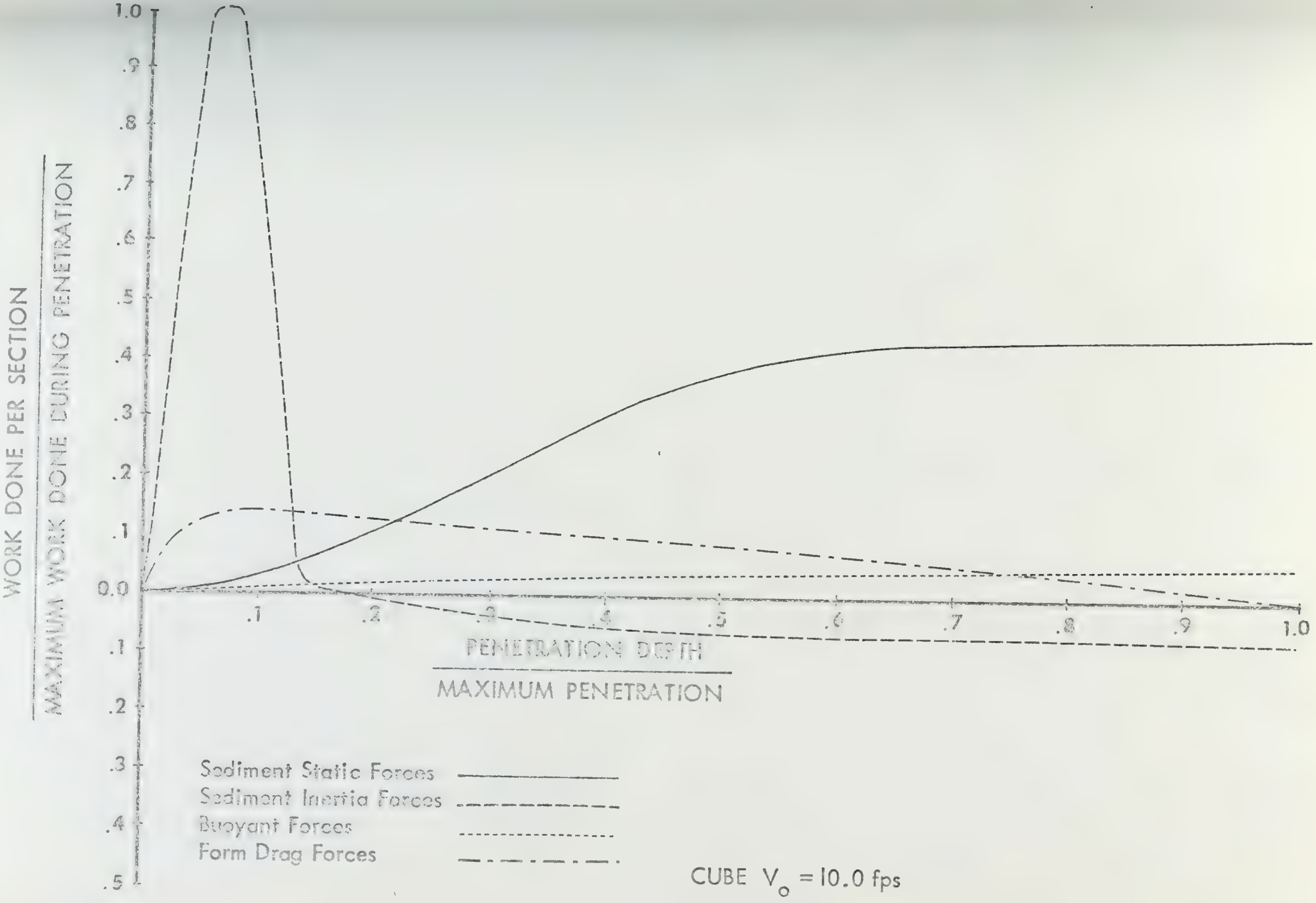
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
CUBE $V_o = 5.0$ fps


WORK DONE PER SECTION
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PENETRATION DEPTH
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Sediment Static Forces
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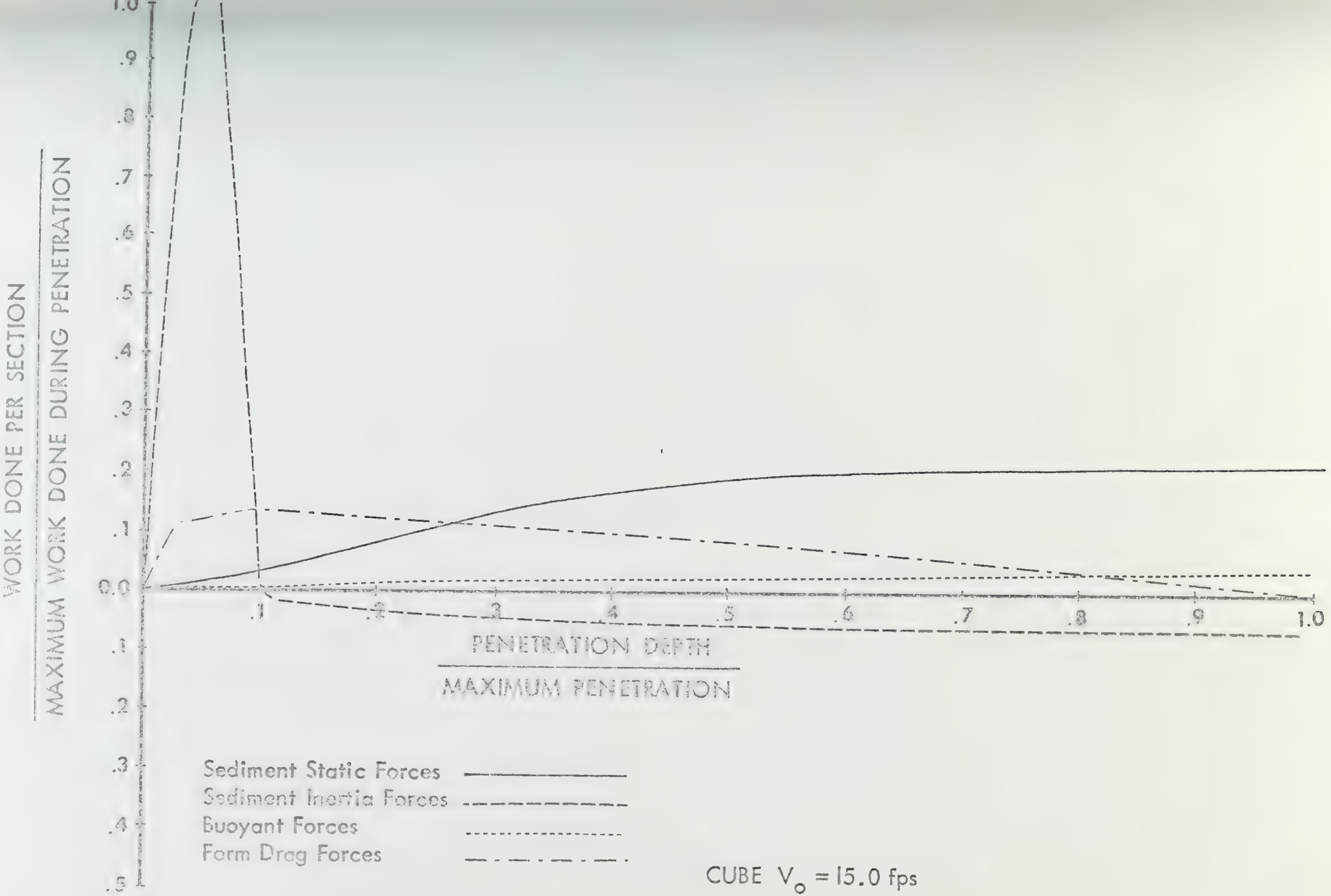
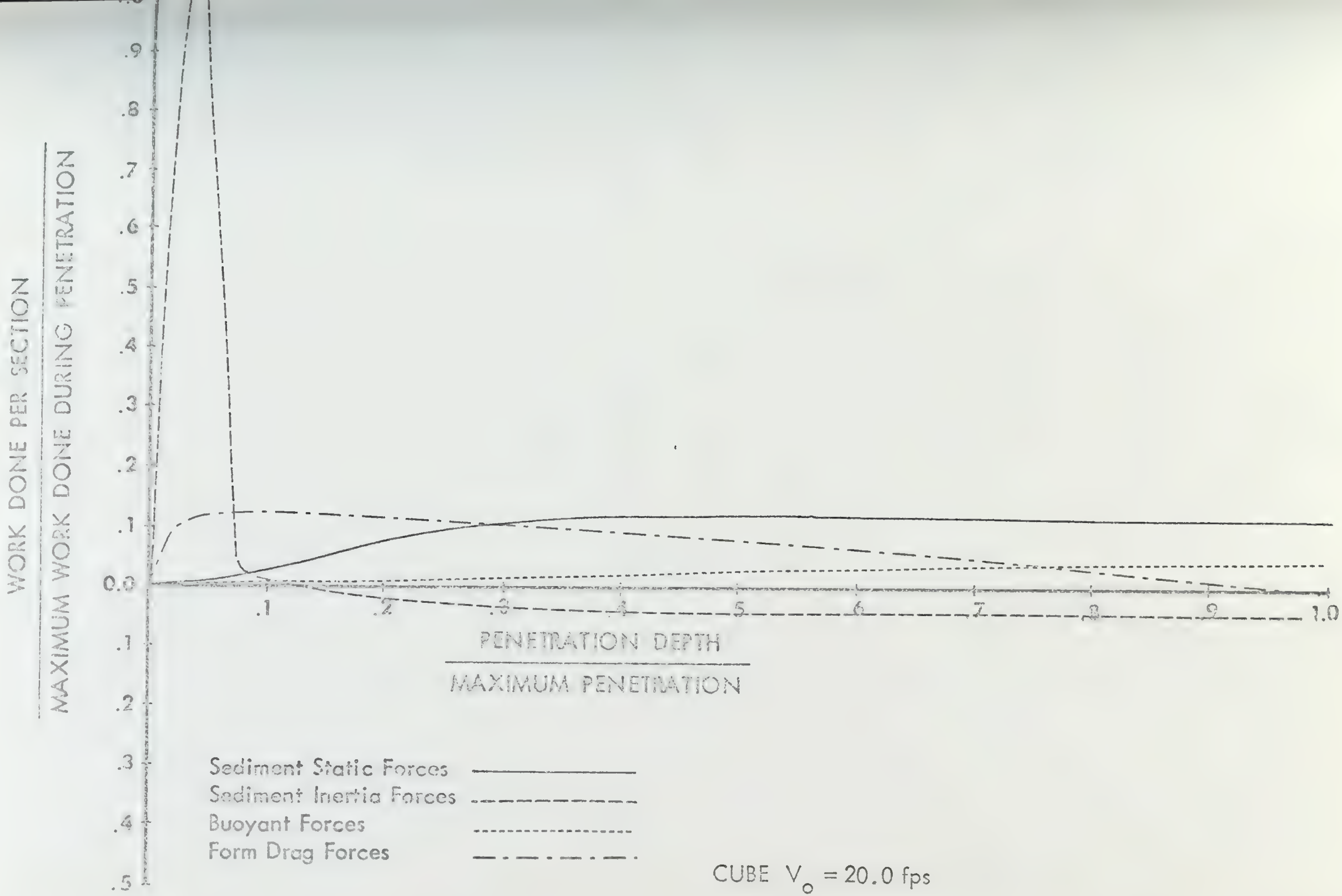
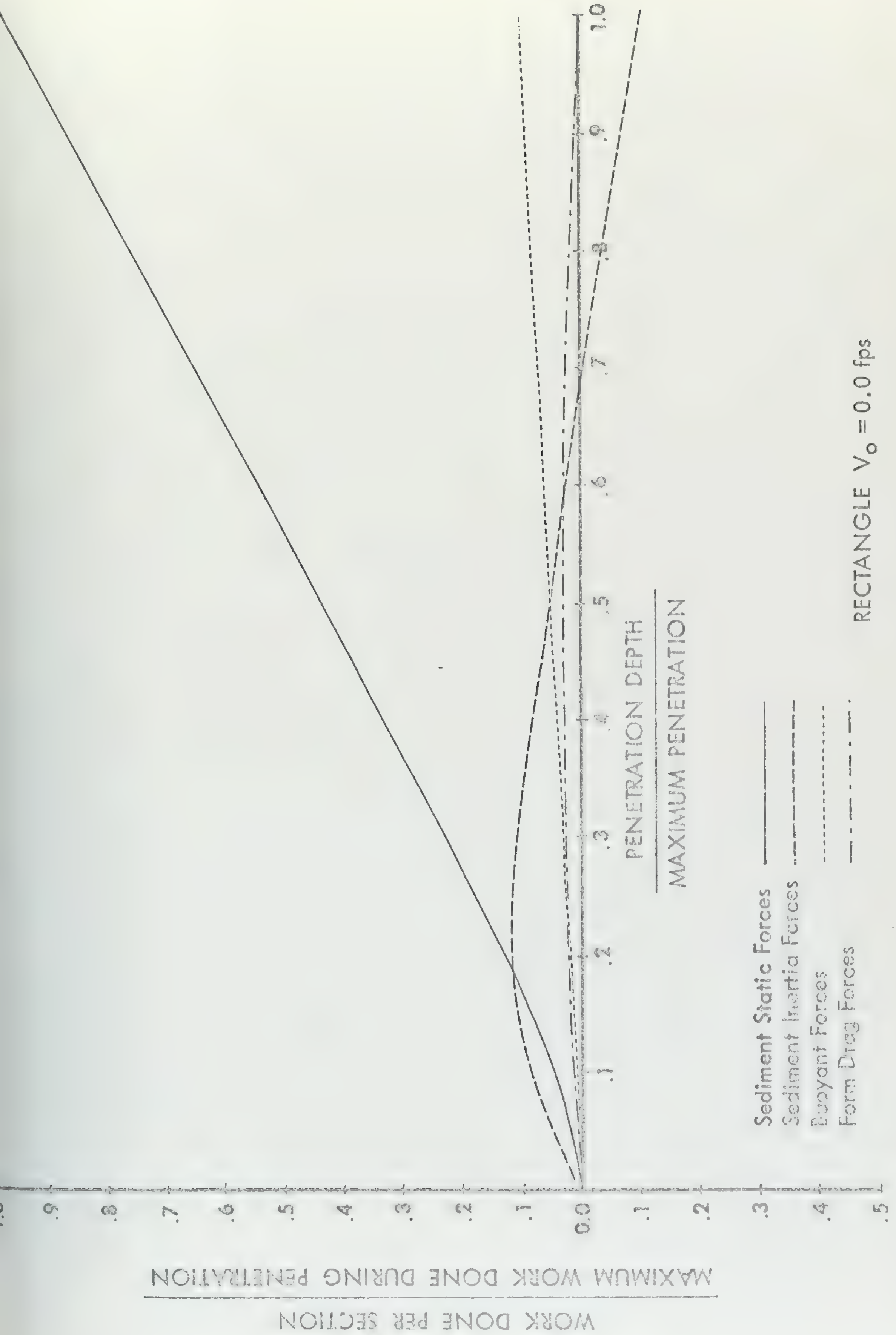
Buoyant Forces
Form Drag Forces
CUBE $V_o = 10.0$ fps



CUBE $V_o = 15.0$ fps



CUBE $V_o = 20.0$ fps


WORK DONE PER SECTION / MAXIMUM WORK DONE DURING PENETRATION
PENETRATION DEPTH / MAXIMUM PENETRATION
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Sediment Static Forces
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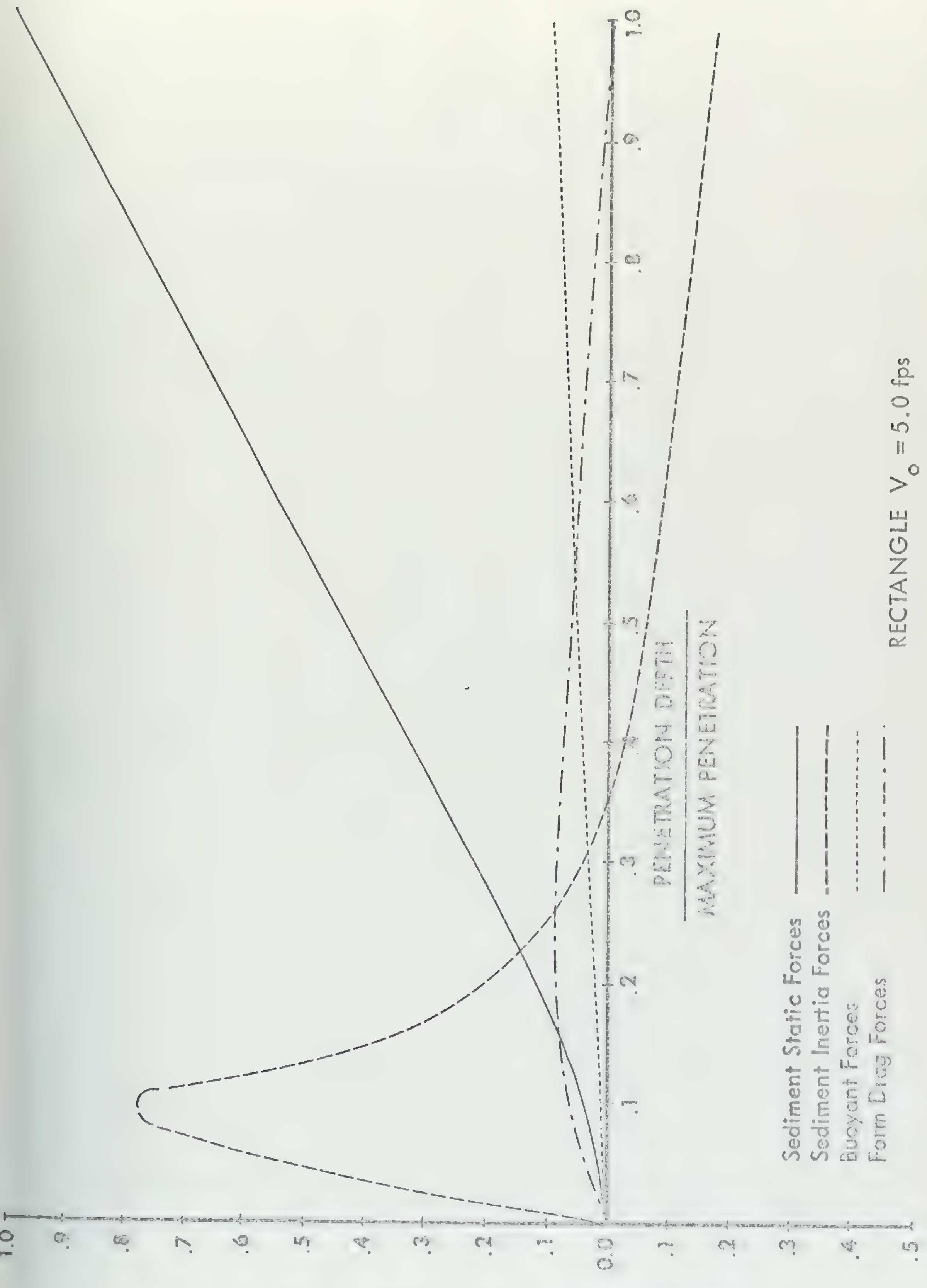
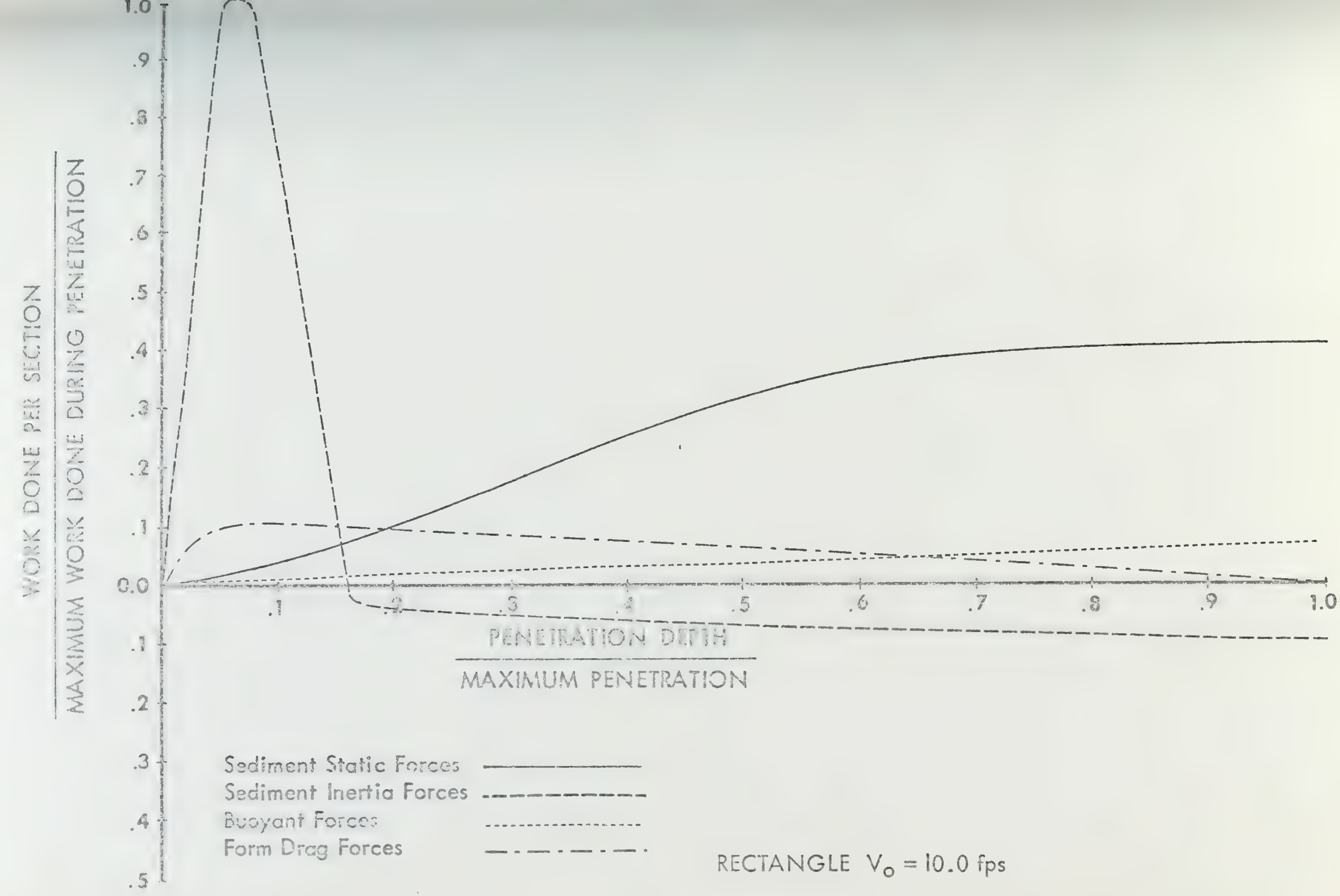
Form Drag Forces
RECTANGLE $V_o = 0.0$ fps



RECTANGLE $V_o = 5.0$ fps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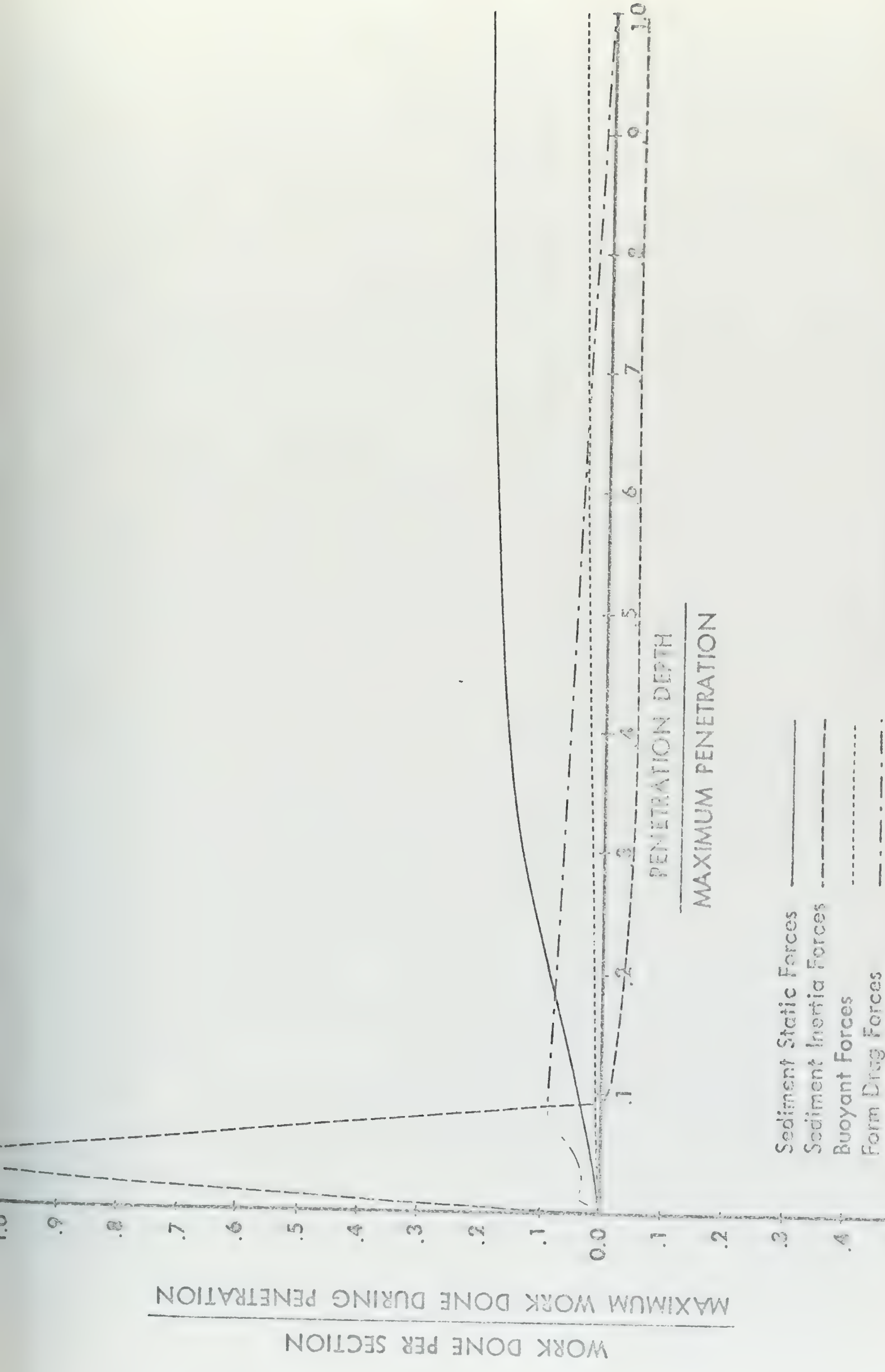
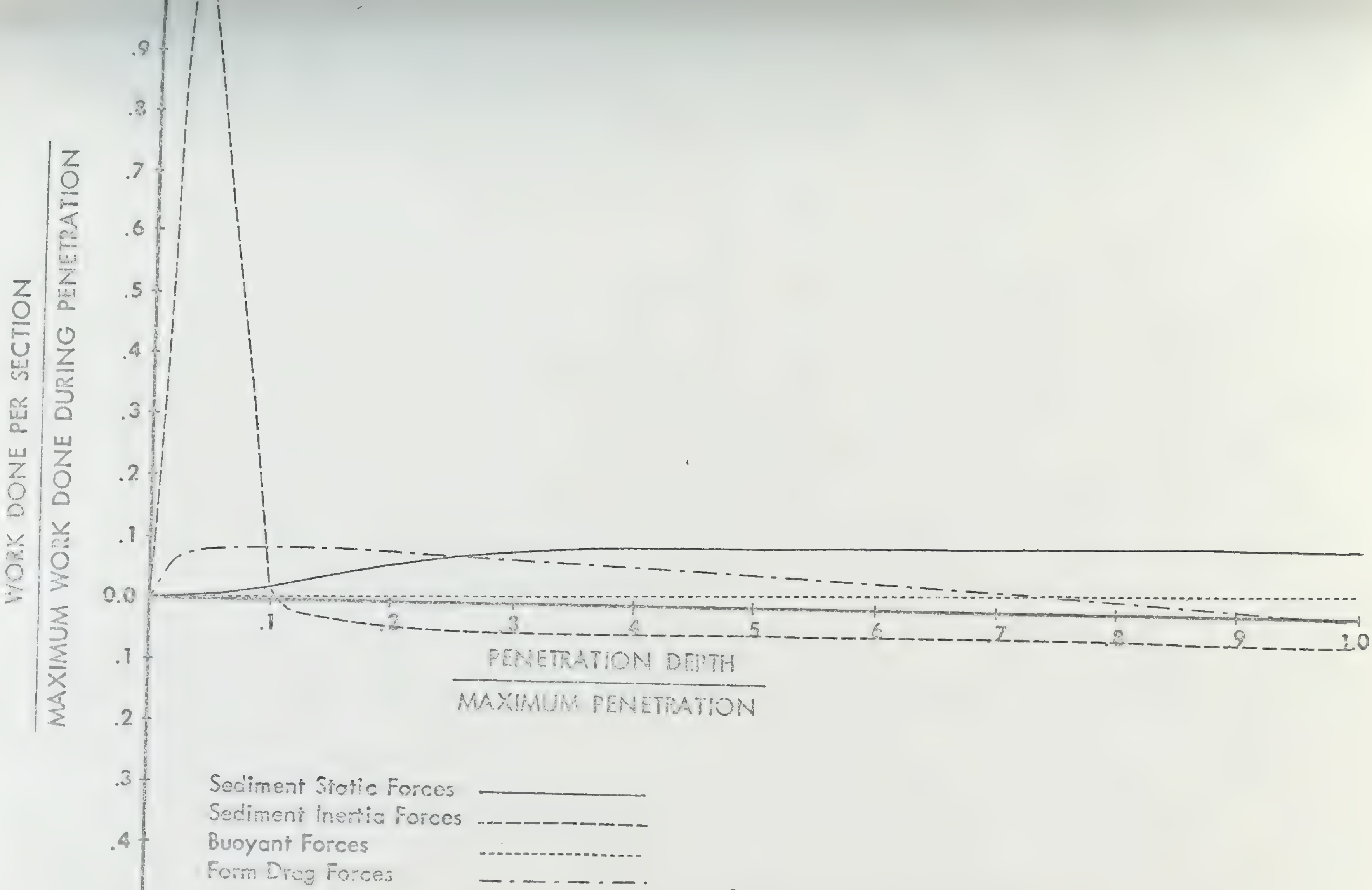
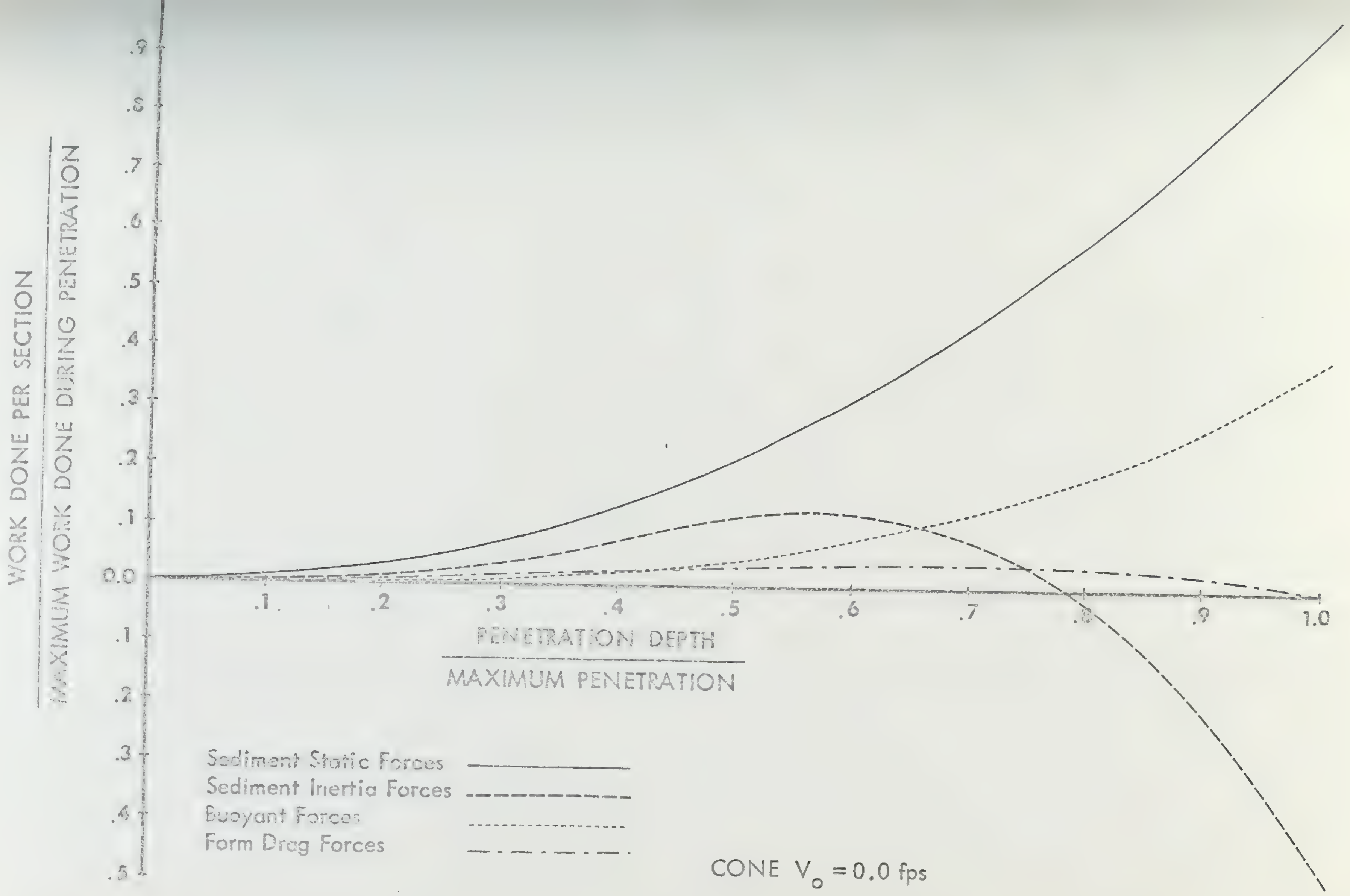
PENETRATION DEPTH
MAXIMUM PENETRATION
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
RECTANGLE $V_o = 10.0$ fps



RECTANGLE $V_o = 15.0$ fps



RECTANGLE $V_o = 20.0$ fps


WORK DONE PER SECTION / MAXIMUM WORK DONE DURING PENETRATION
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PENETRATION DEPTH / MAXIMUM PENETRATION
Sediment Static Forces
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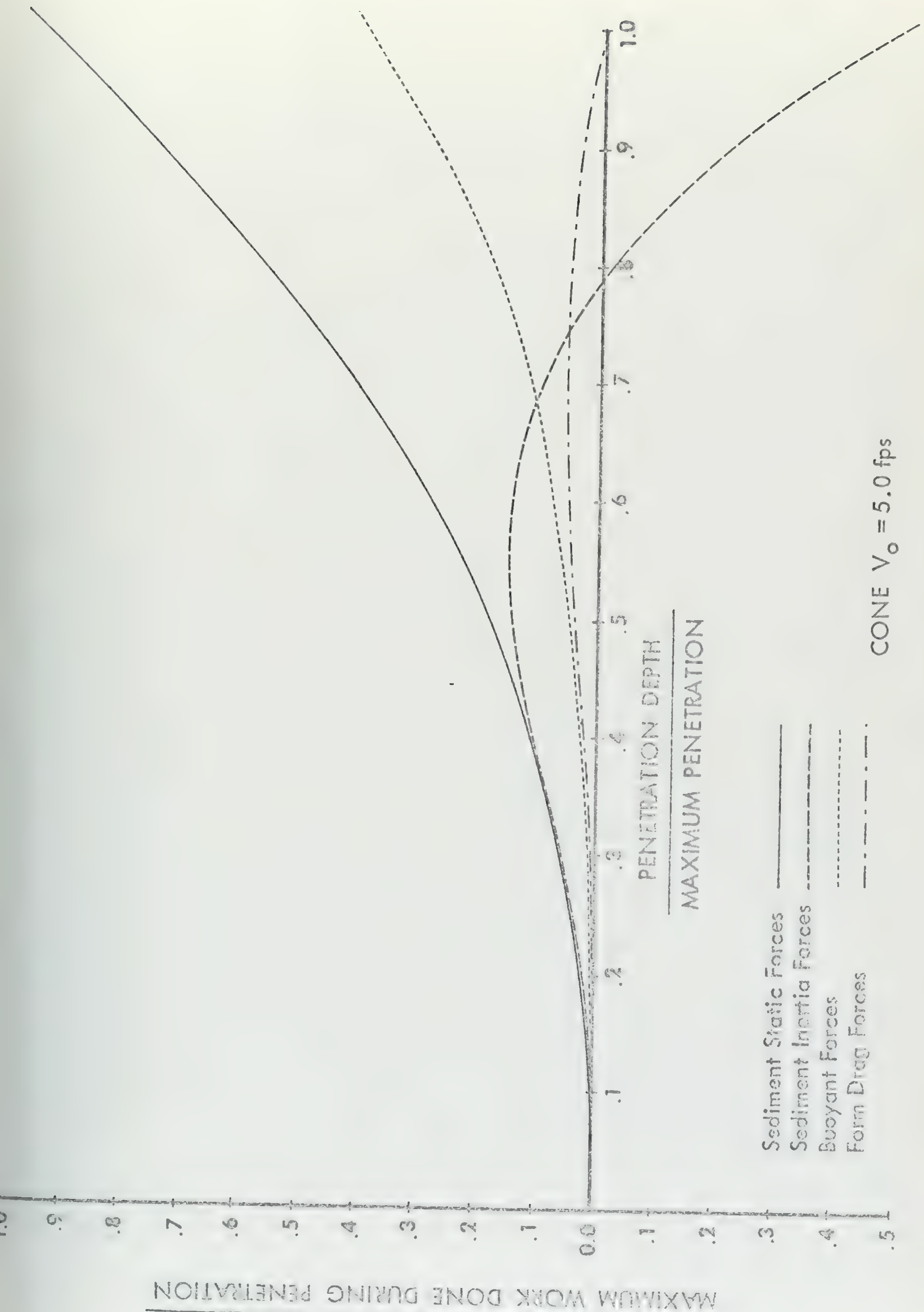
Buoyant Forces
Form Drag Forces
CONE $V_o = 0.0$ fps


WORK DONE PER SECTION
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PENETRATION DEPTH
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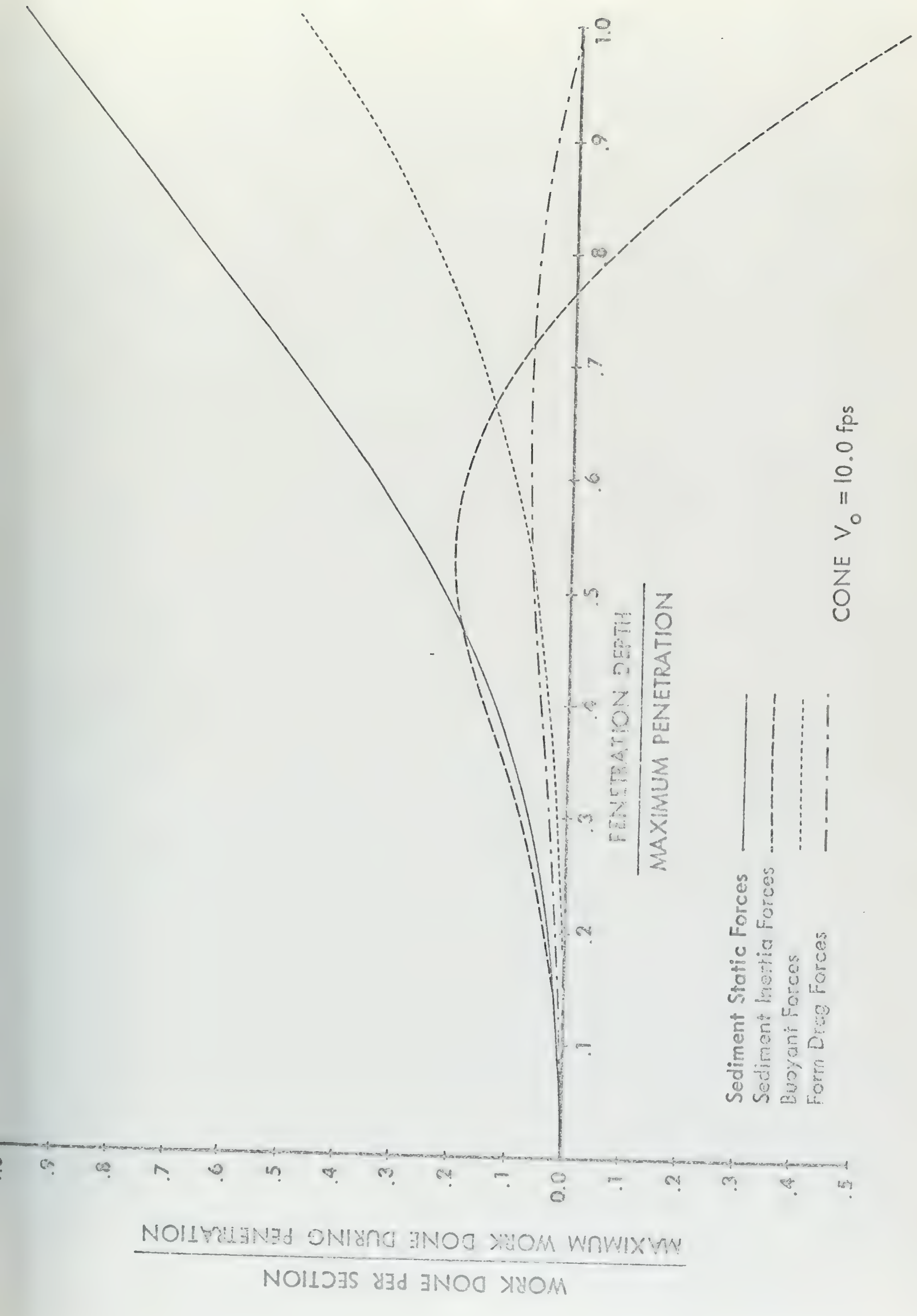
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
CONE $V_o = 5.0$ fps


WORK DONE PER SECTION
MAXIMUM WORK DONE DURING PENETRATION
PENETRATION DEPTH
MAXIMUM PENETRATION
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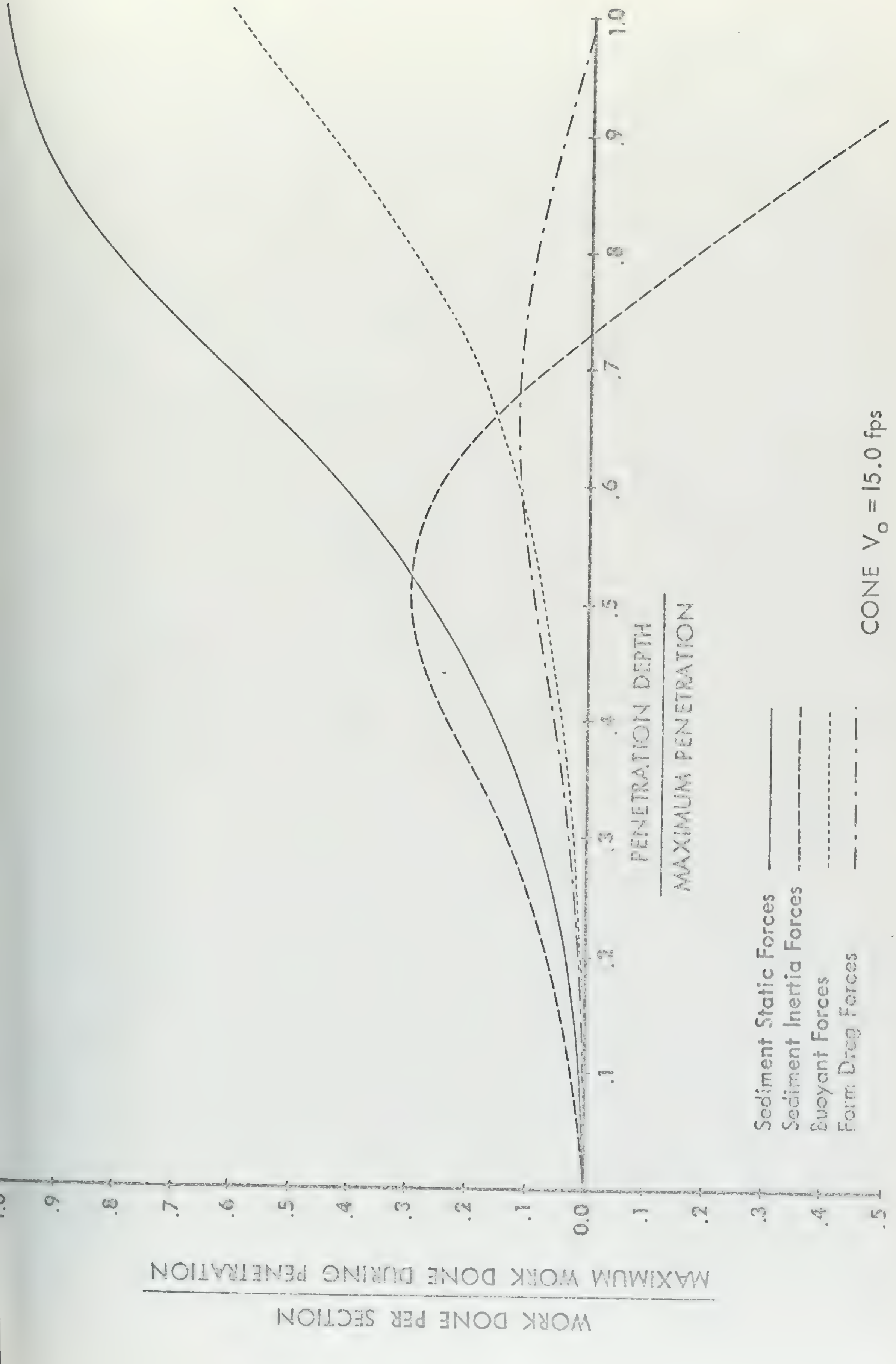
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
CONE V_o = 10.0 fps


WORK DONE PER SECTION
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PENETRATION DEPTH
MAXIMUM PENETRATION
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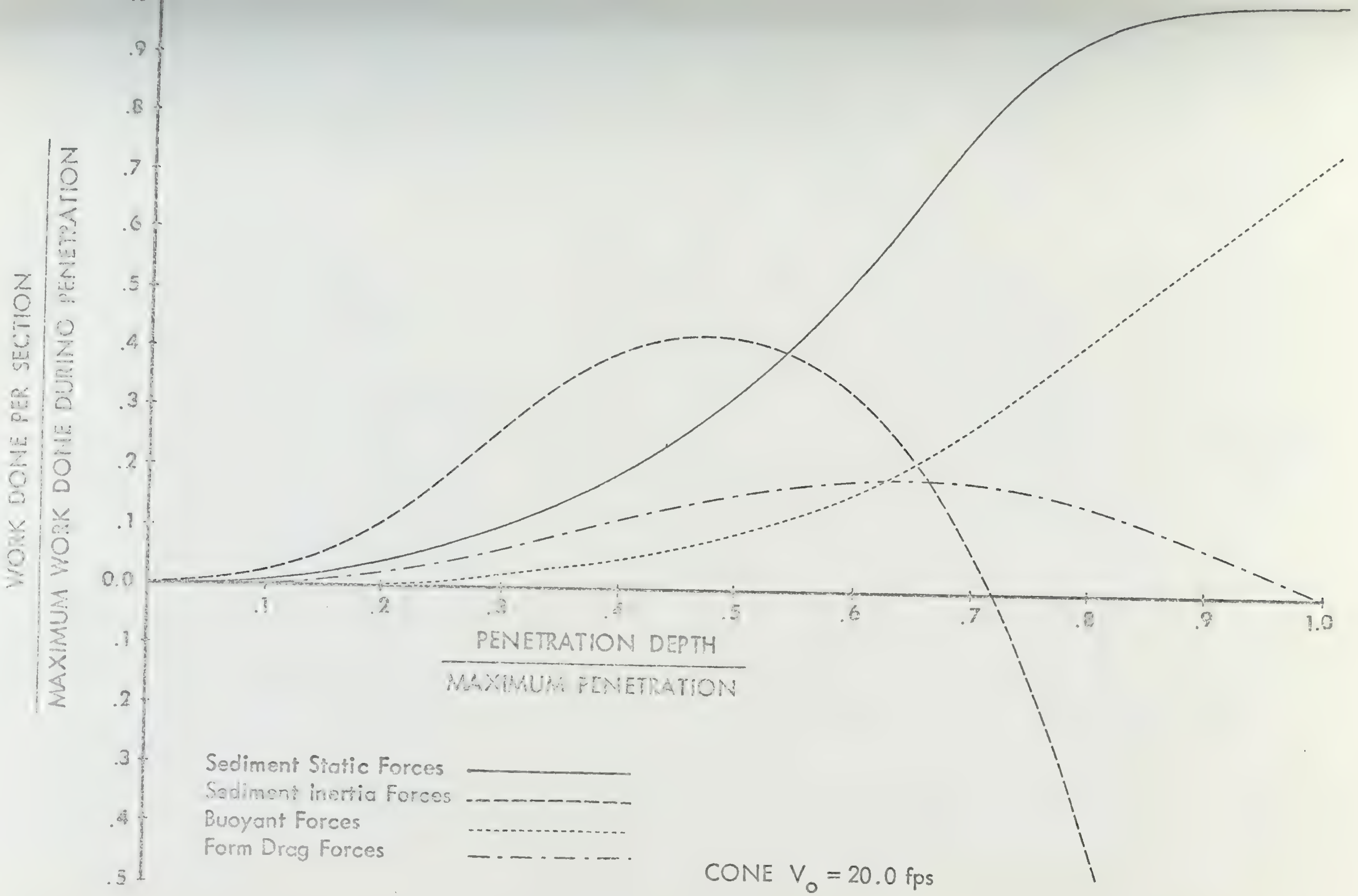
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
CONE $V_o = 15.0$ fps


WORK DONE PER SECTION
MAXIMUM WORK DONE DURING PENETRATION
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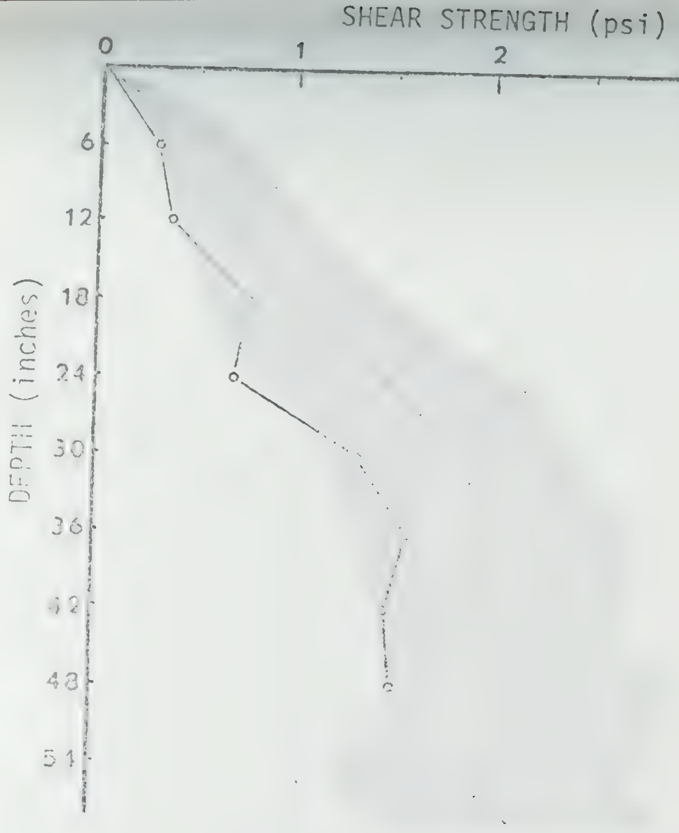
PENETRATION DEPTH
MAXIMUM PENETRATION
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
CONE $V_o = 20.0$ fps

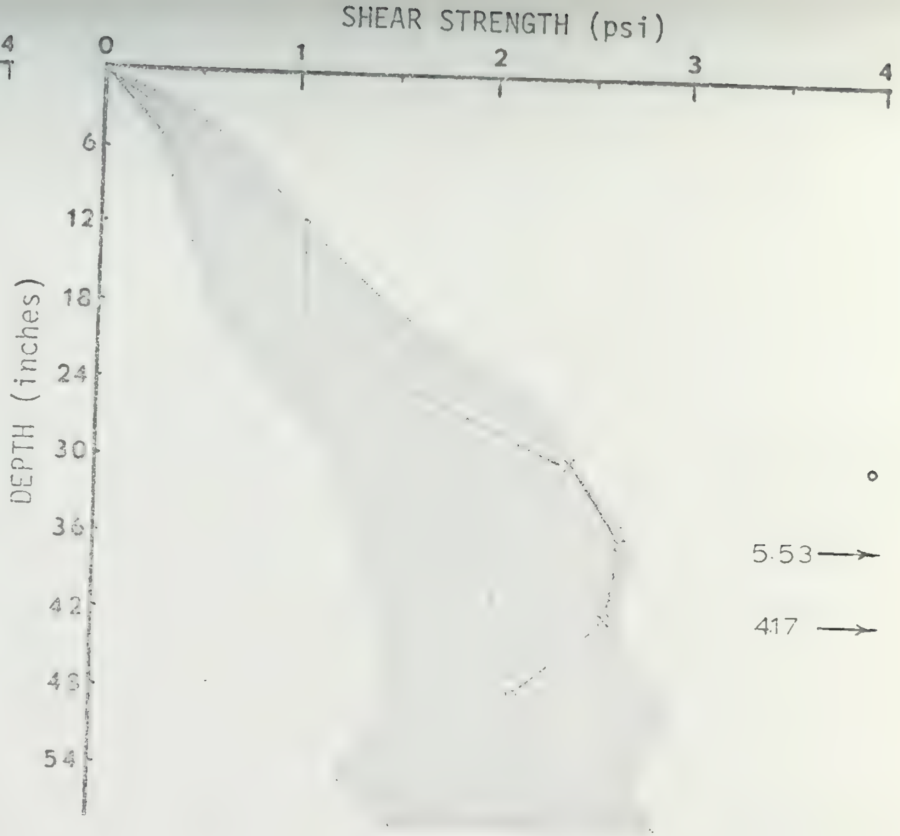
APPENDIX B

SHEAR STRENGTH PROFILES OF THE TEST PIT

The shear strength profiles at each drop station are illustrated together with the adjusted profile used in the penetration prediction computation. The profiles are in the same order as listed in Table VII.

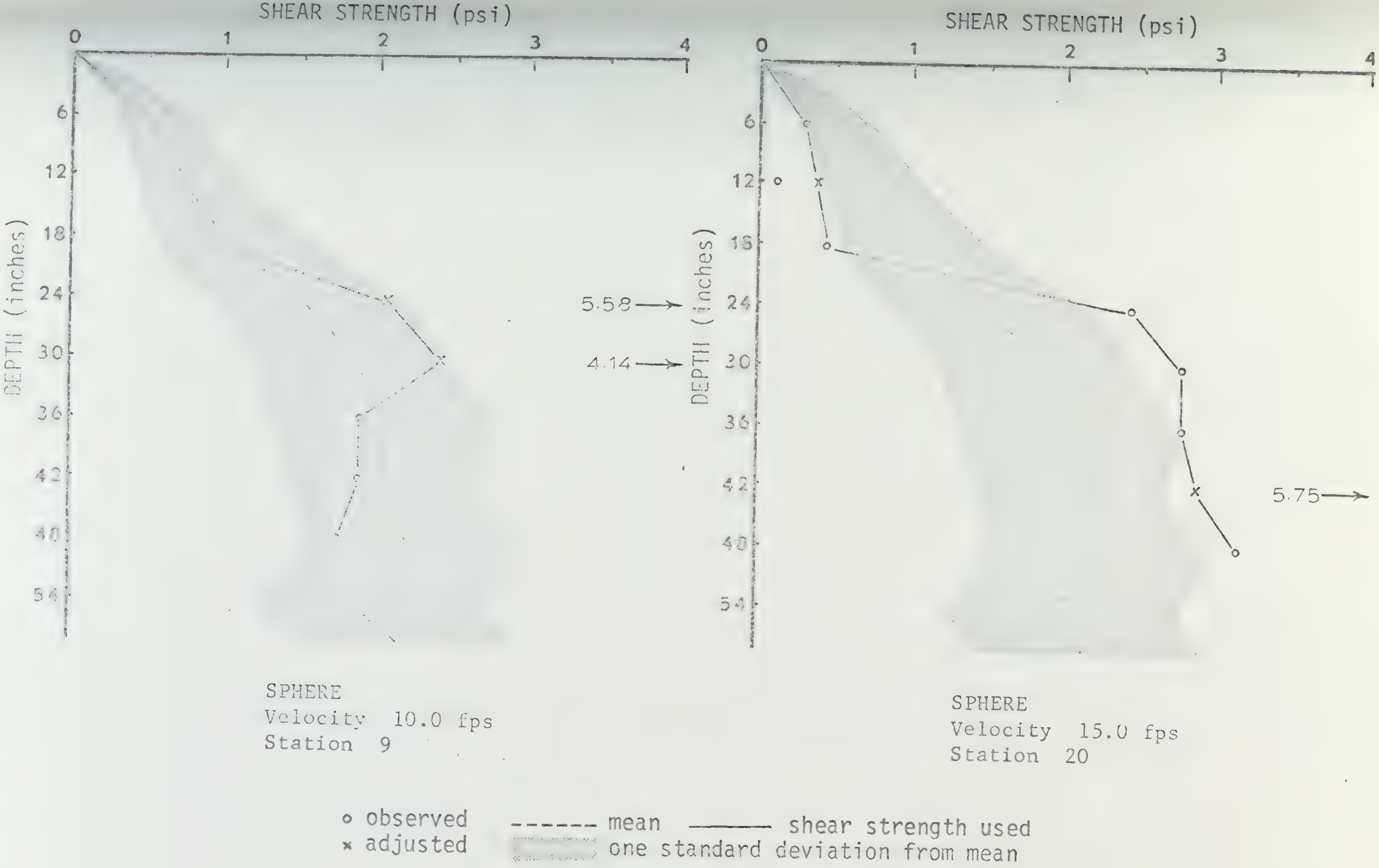


SPHERE
Velocity 0.0 fps
Station 6



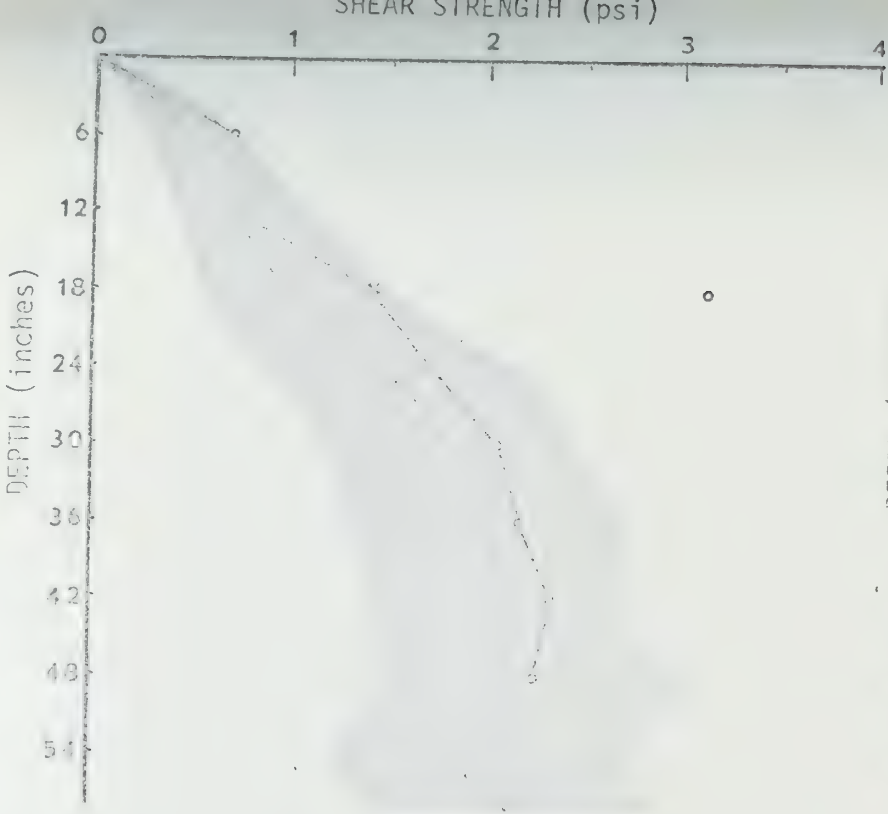
SPHERE
Velocity 5.0 fps
Station 7

○ observed
× adjusted
------ mean
——— shear strength used
▨ one standard deviation from mean

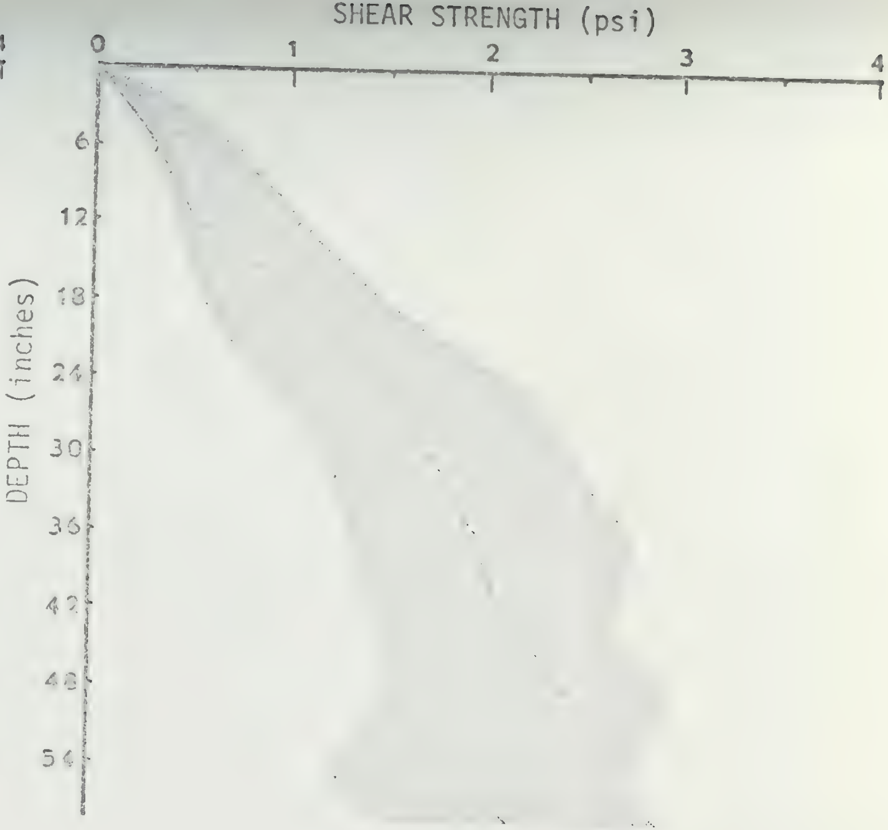


SPHERE
Velocity 10.0 fps
Station 9

SPHERE
Velocity 15.0 fps
Station 20



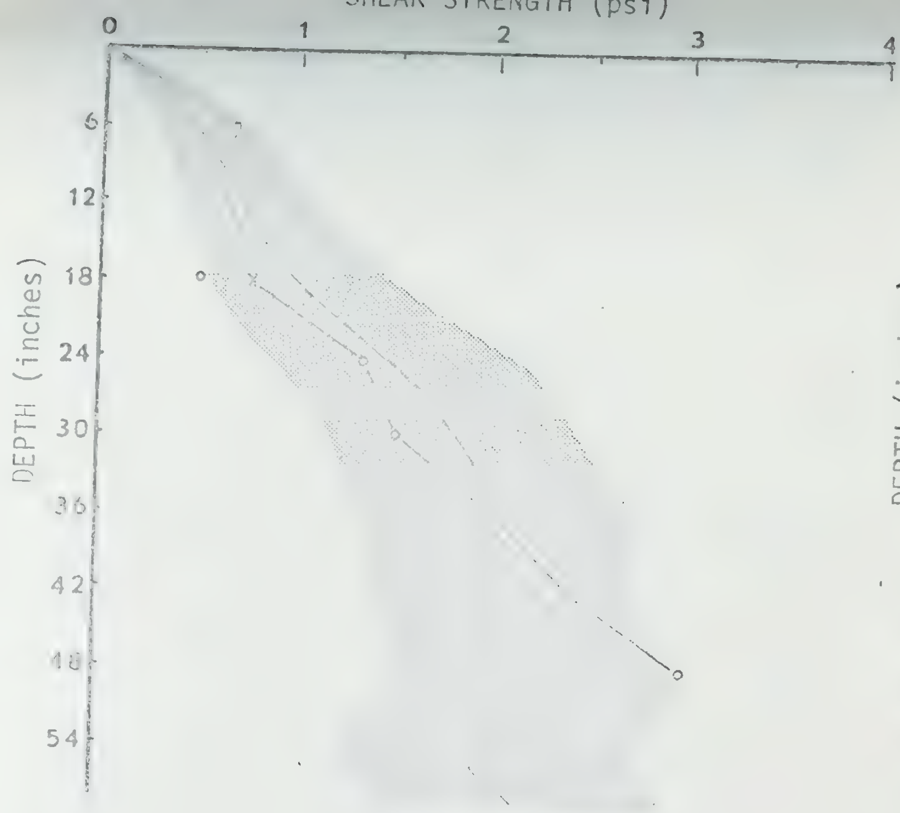
SPHERE
Velocity 20.0 fps
Station 26



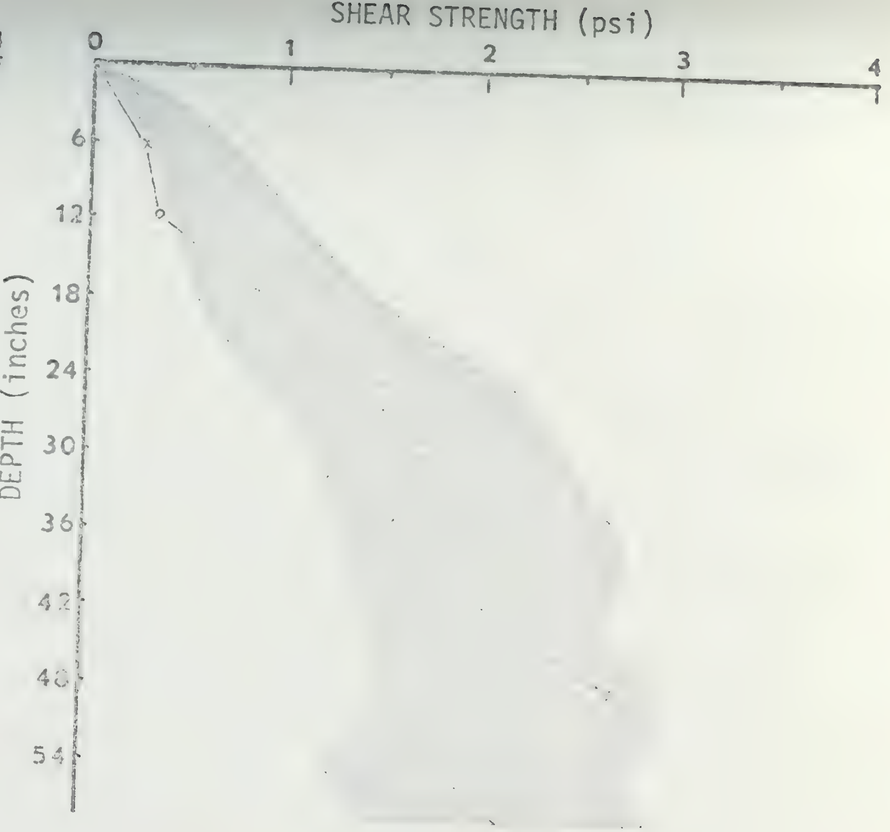
SPHERE
Velocity 5.0 fps
Station 15

- o observed
- × adjusted

------	mean
▨	one standard deviation from mean
———	shear strength used



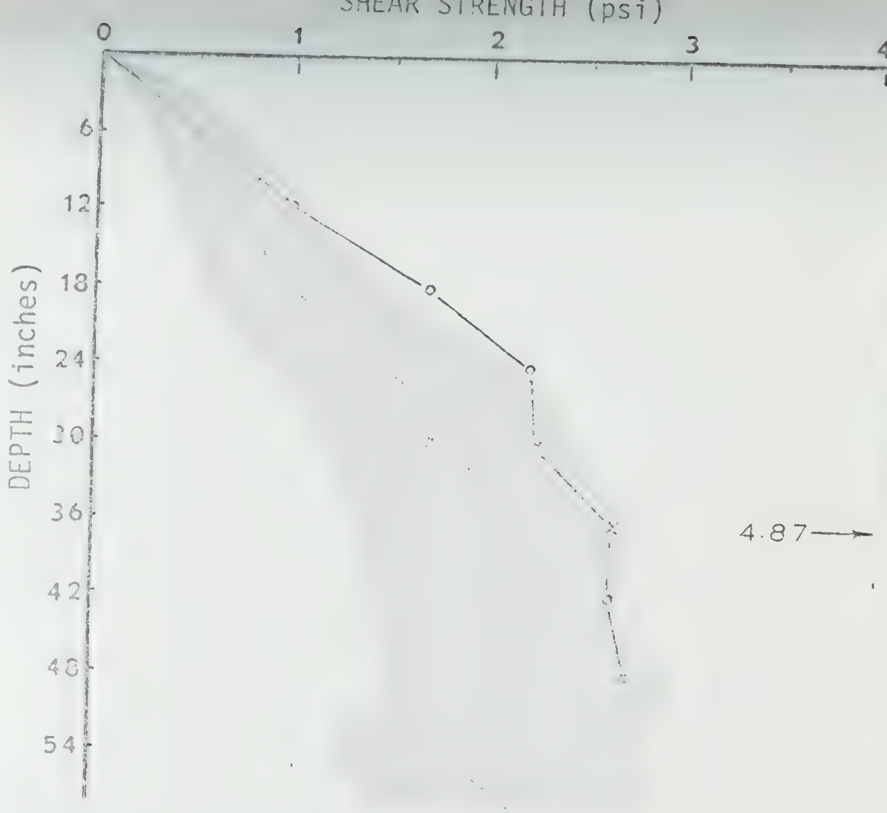
SPHERE
Velocity 10.0 fps
Station -



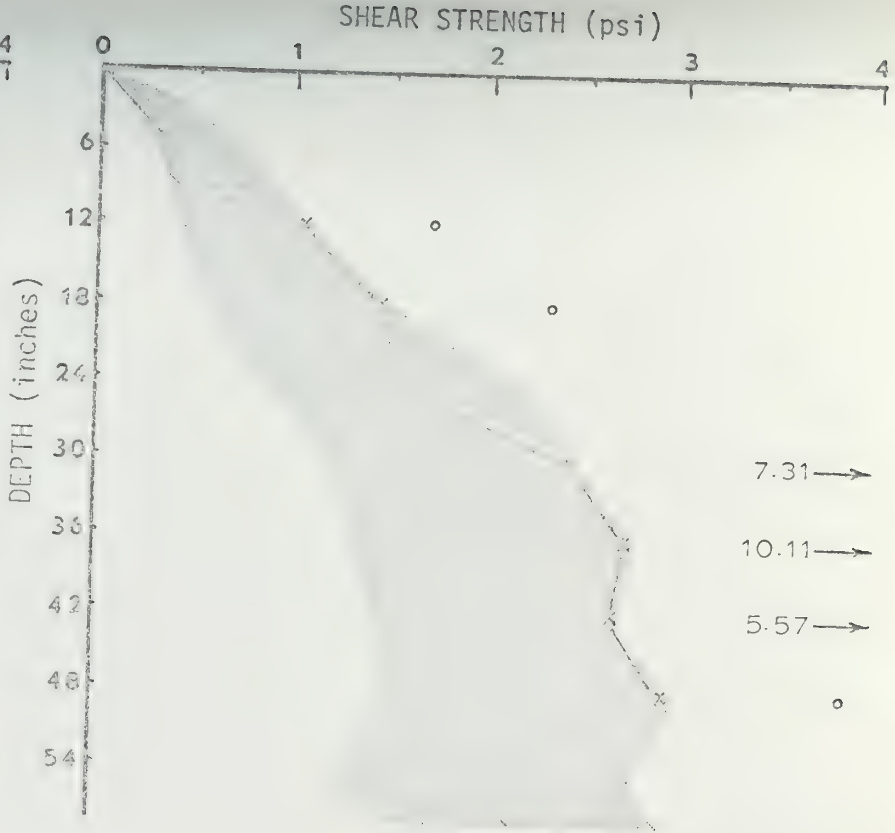
SPHERE
Velocity 15.0 fps
Station -

o observed
× adjusted

------ mean ——— shear strength used
▨ one standard deviation from mean



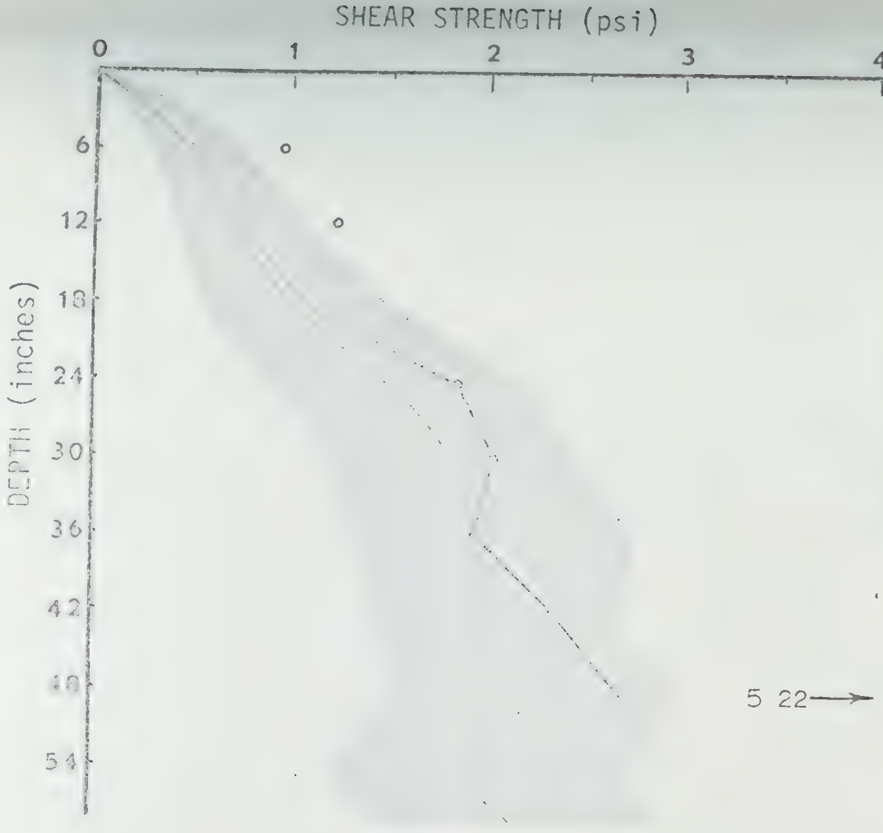
SPHERE
Velocity 20.0 fps
Station -



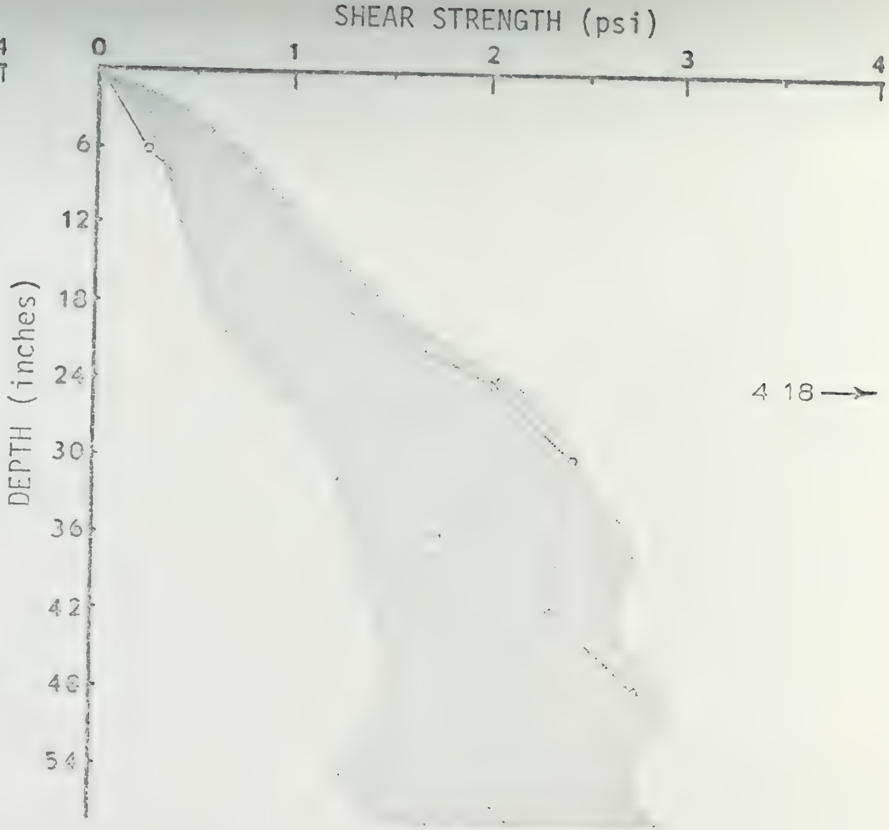
HORIZONTAL CYLINDER
Velocity 0.0 fps
Station 23

o observed
× adjusted

------ mean
——— shear strength used
▨ one standard deviation from mean



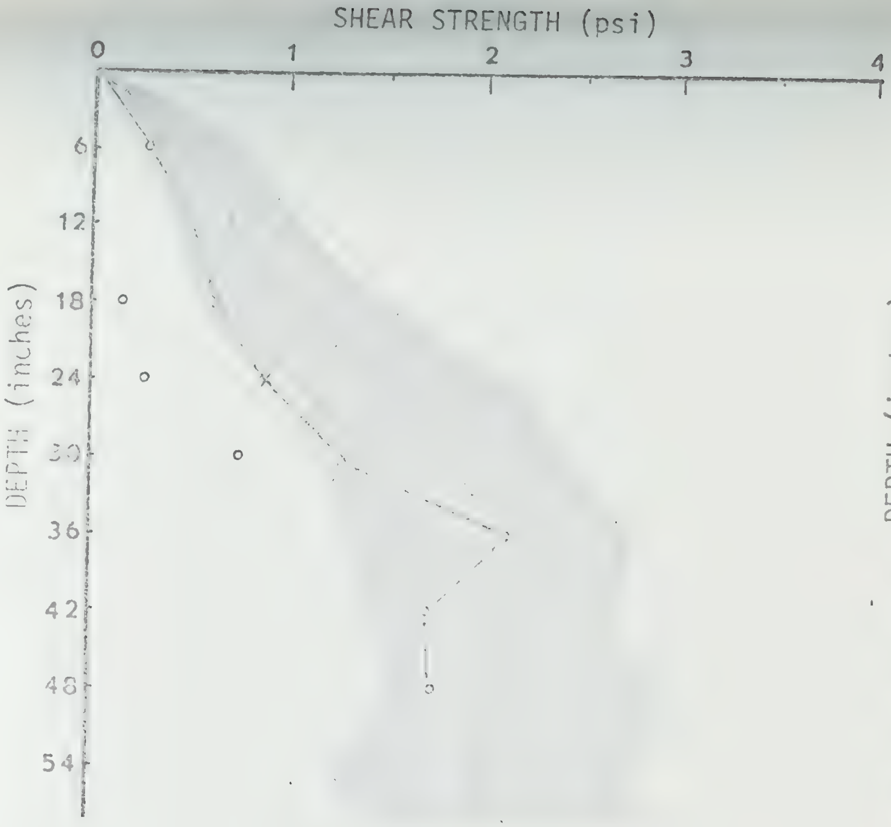
HORIZONTAL CYLINDER
Velocity 5.0 fps
Station 15



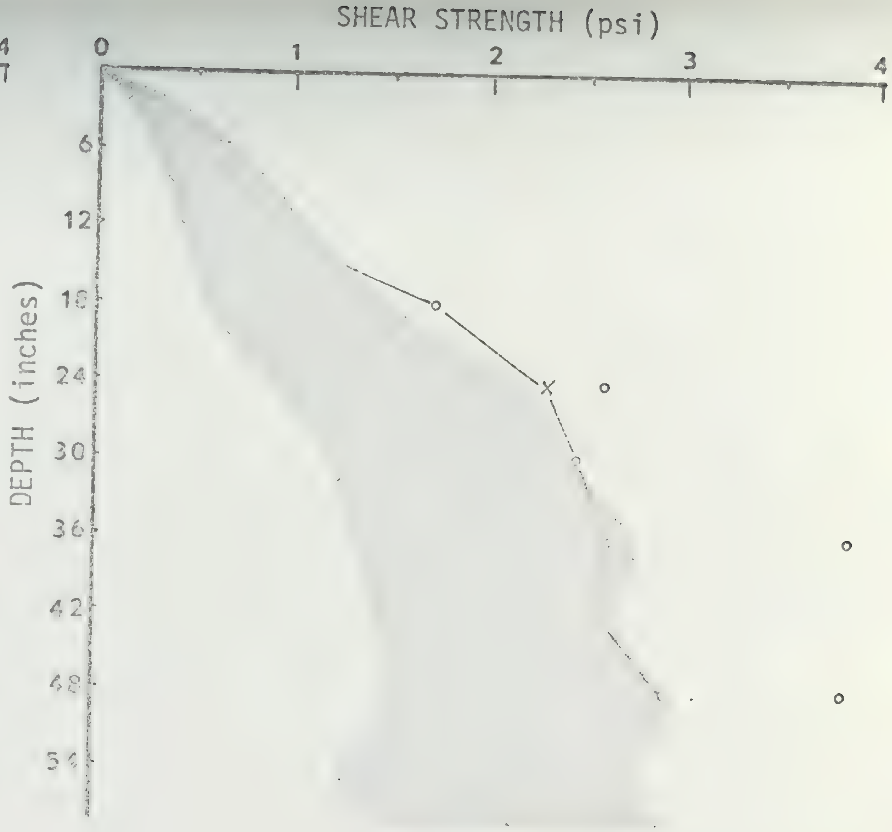
HORIZONTAL CYLINDER
Velocity 10.0 fps
Station 21

○ observed
× adjusted

------ mean
——— shear strength used
▨ one standard deviation from mean

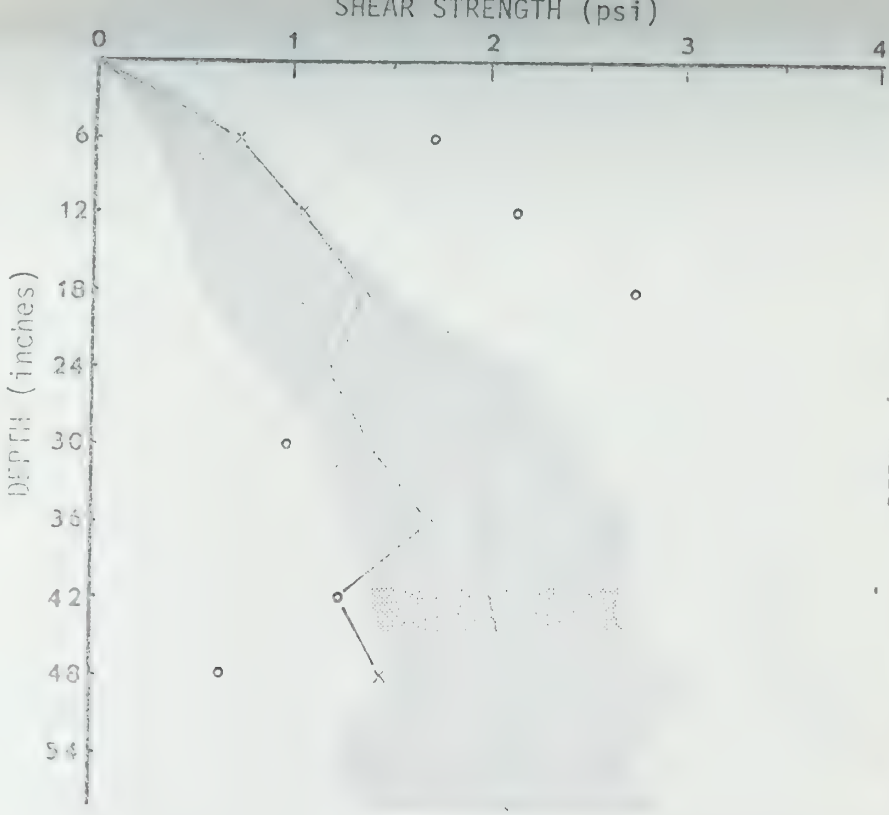


HORIZONTAL CYLINDER
Velocity 15.0 fps
Station 16

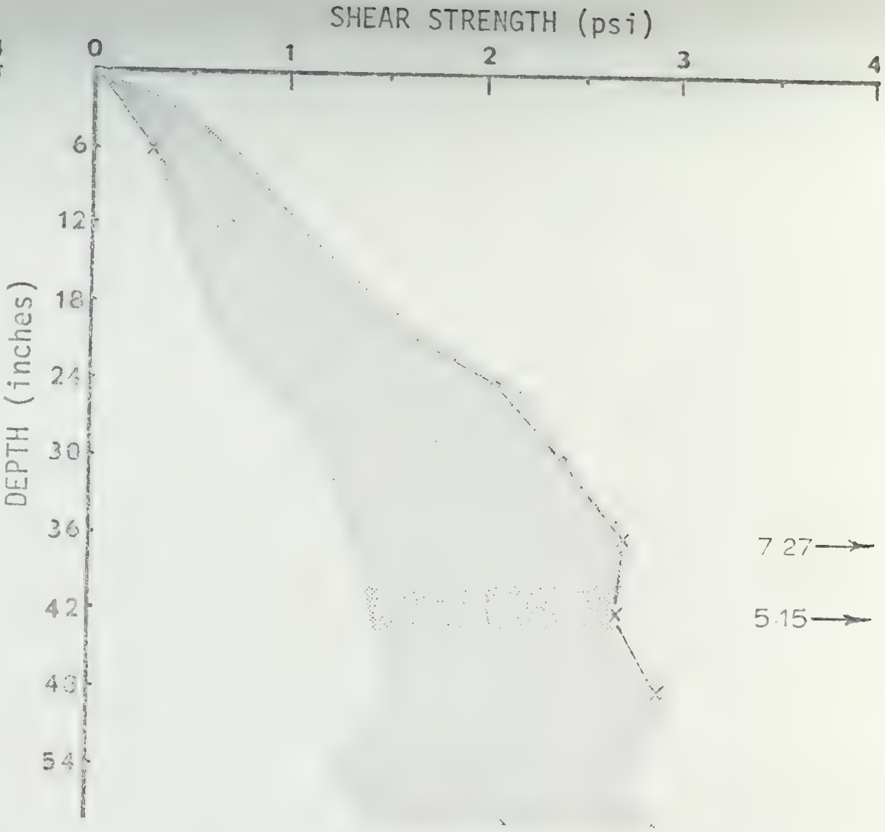


HORIZONTAL CYLINDER
Velocity 20.0 fps
Station 22

○ observed ------ mean ——— shear strength used
× adjusted ▨ one standard deviation from mean

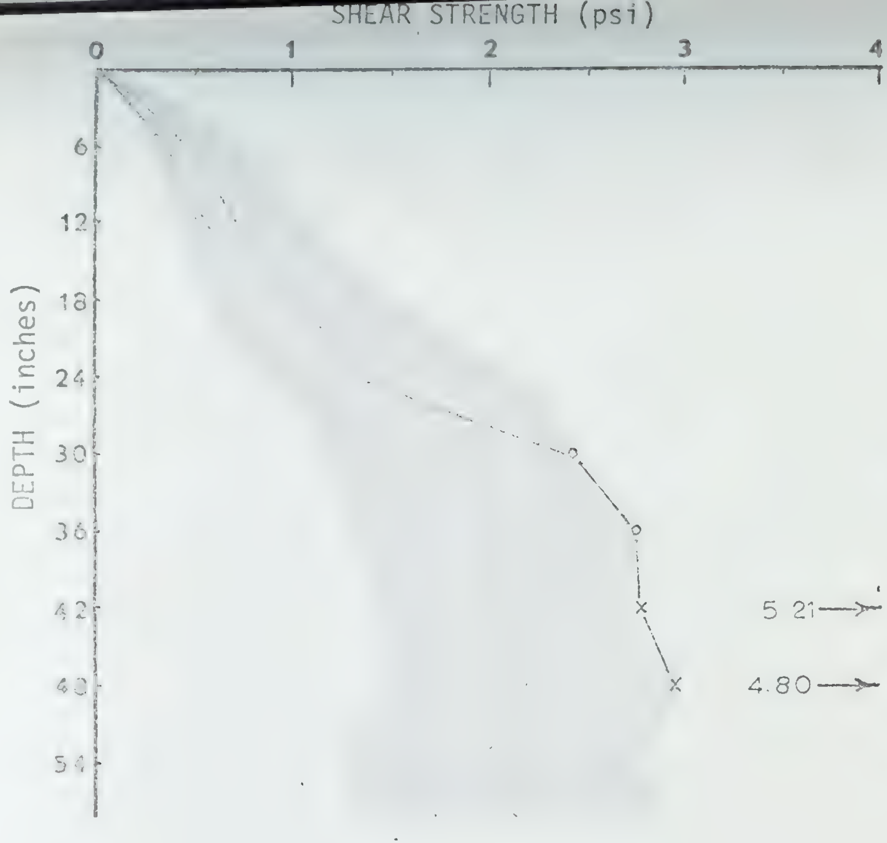


HORIZONTAL CYLINDER
Velocity 20.0 fps
Station 12

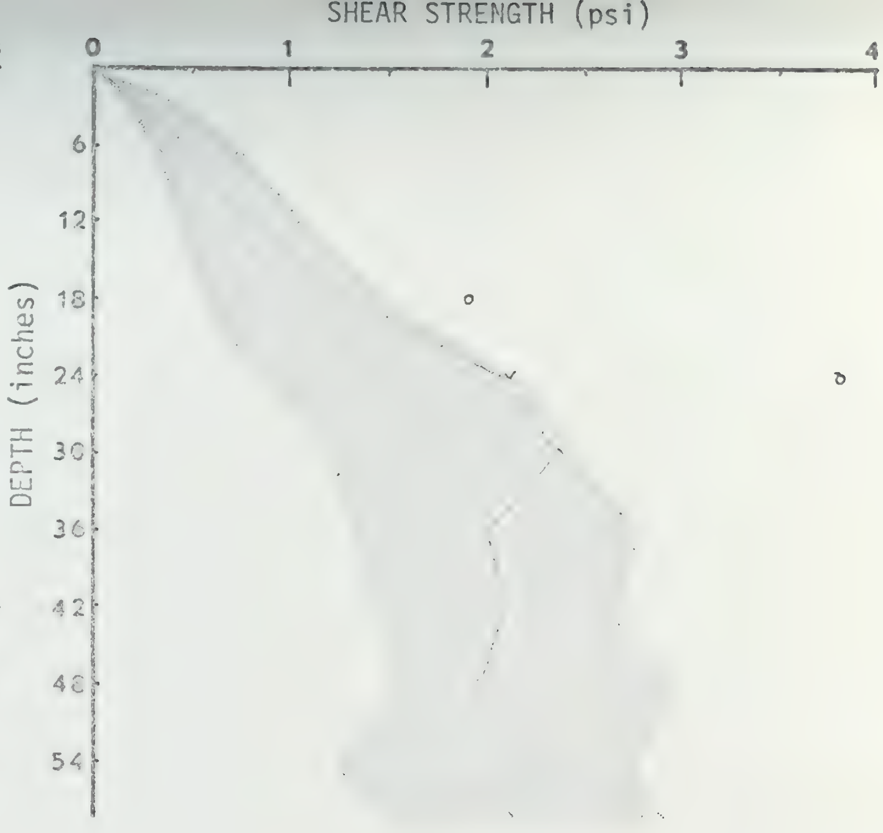


CYLINDER ON END
Velocity 5.0 fps
Station -

○ observed ------ mean —— shear strength used
× adjusted ▨ one standard deviation from mean

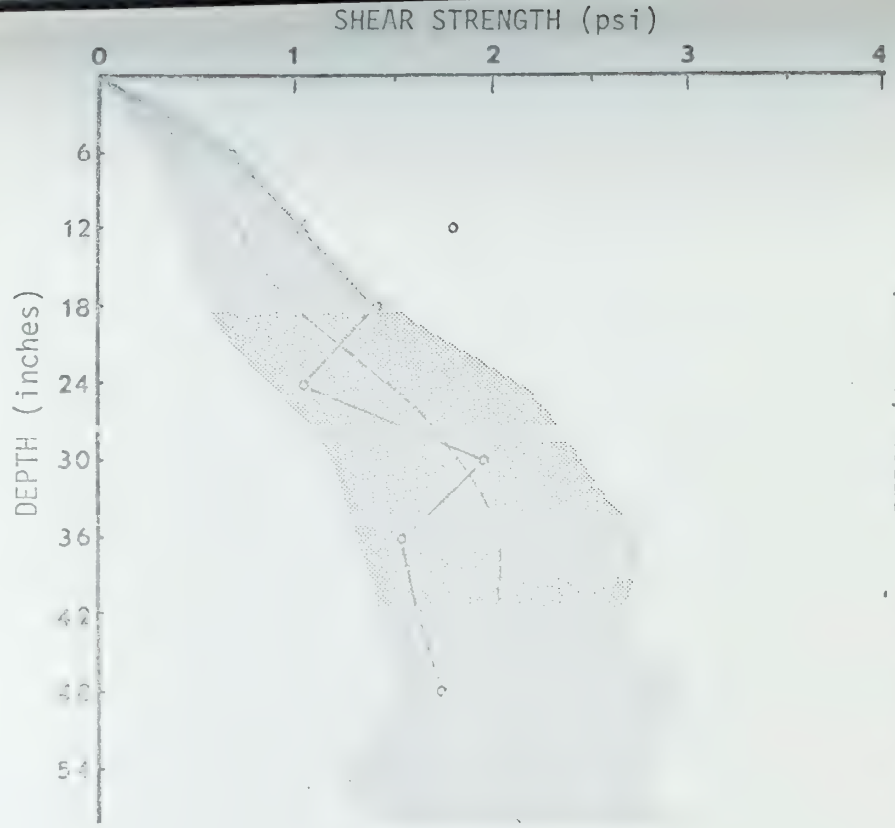


CYLINDER ON END
Velocity 10.0 fps
Station -

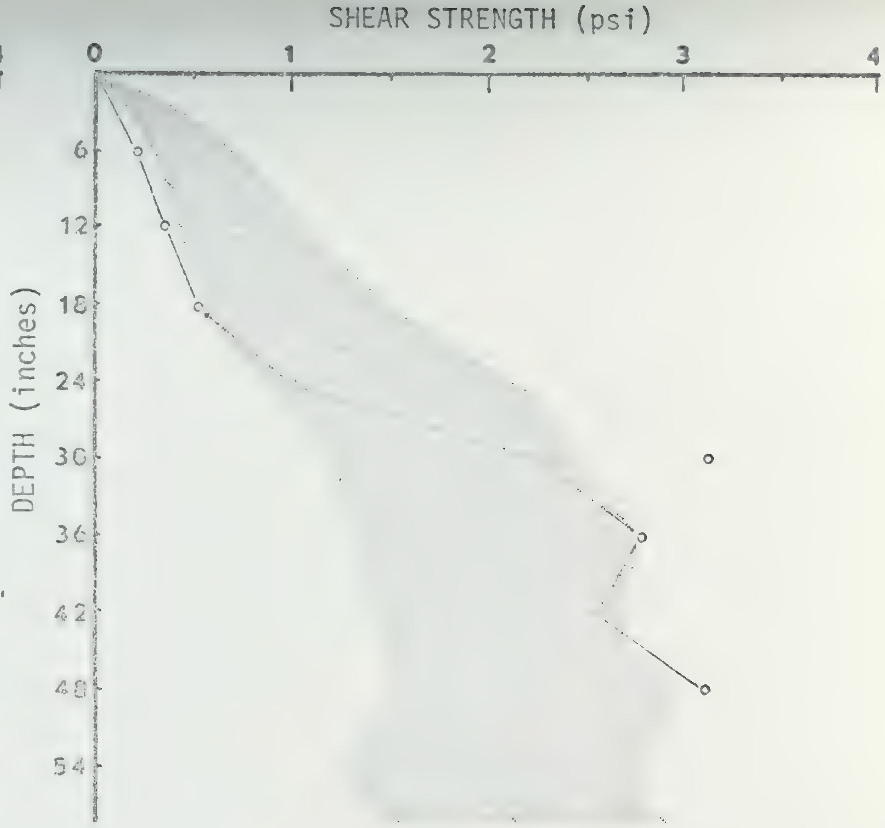


CYLINDER ON END
Velocity 15.0 fps
Station -

○ observed ------ mean ——— shear strength used
× adjusted ▨ one standard deviation from mean

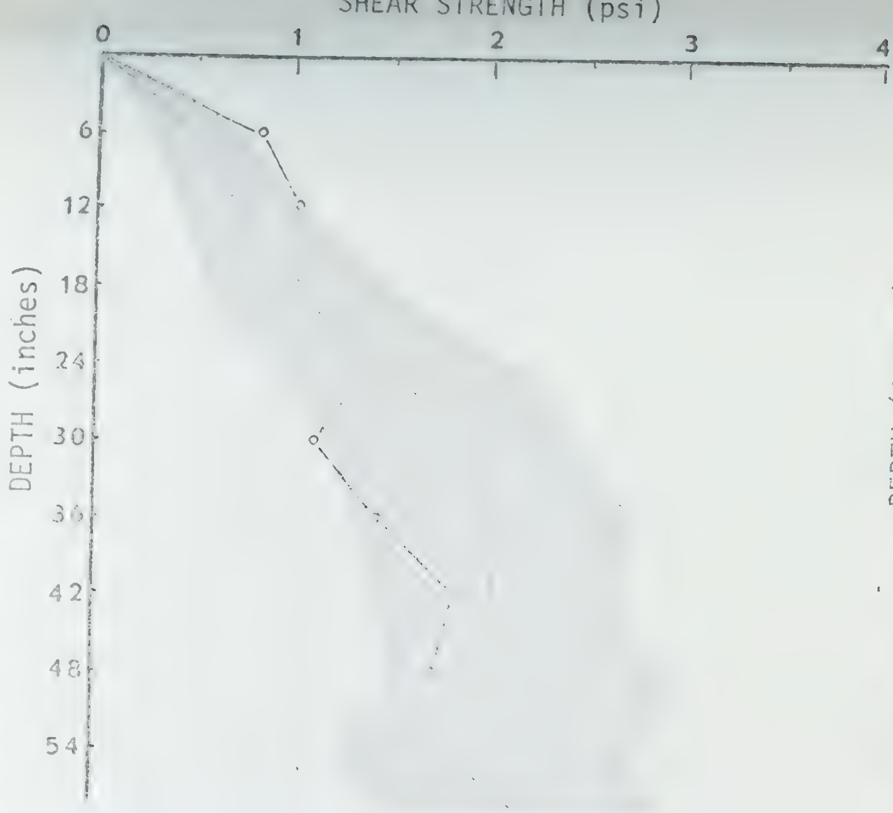


CYLINDER ON END
Velocity 20.0 fps
Station -

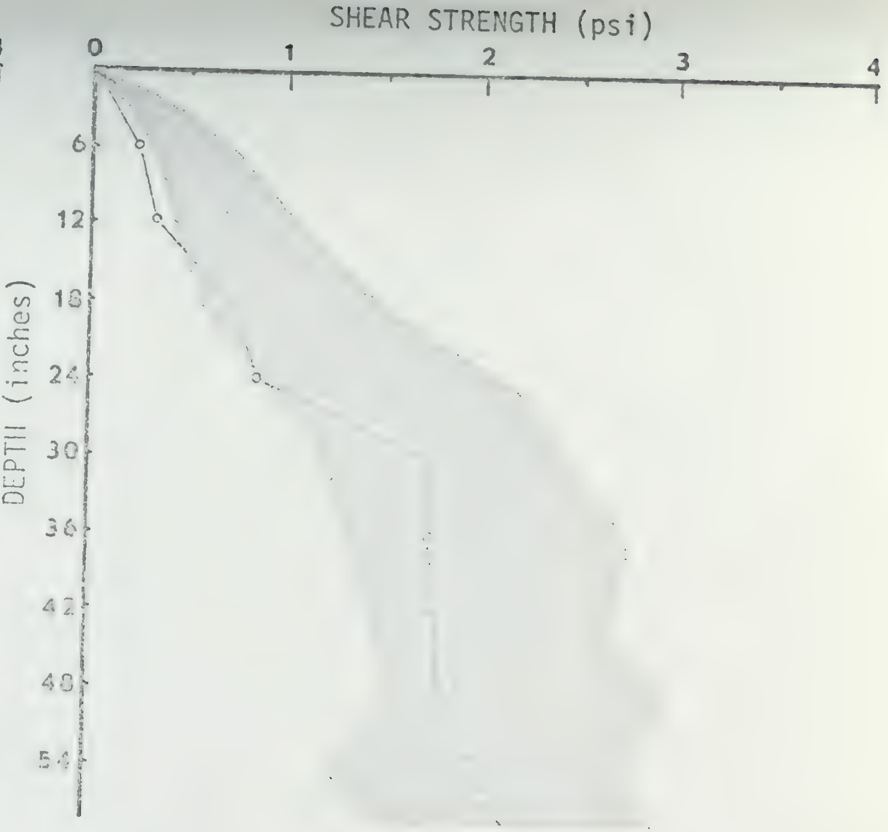


CYLINDER ON END
Velocity 0.0 fps
Station 22

o observed ------ mean ——— shear strength used
× adjusted ▨ one standard deviation from mean

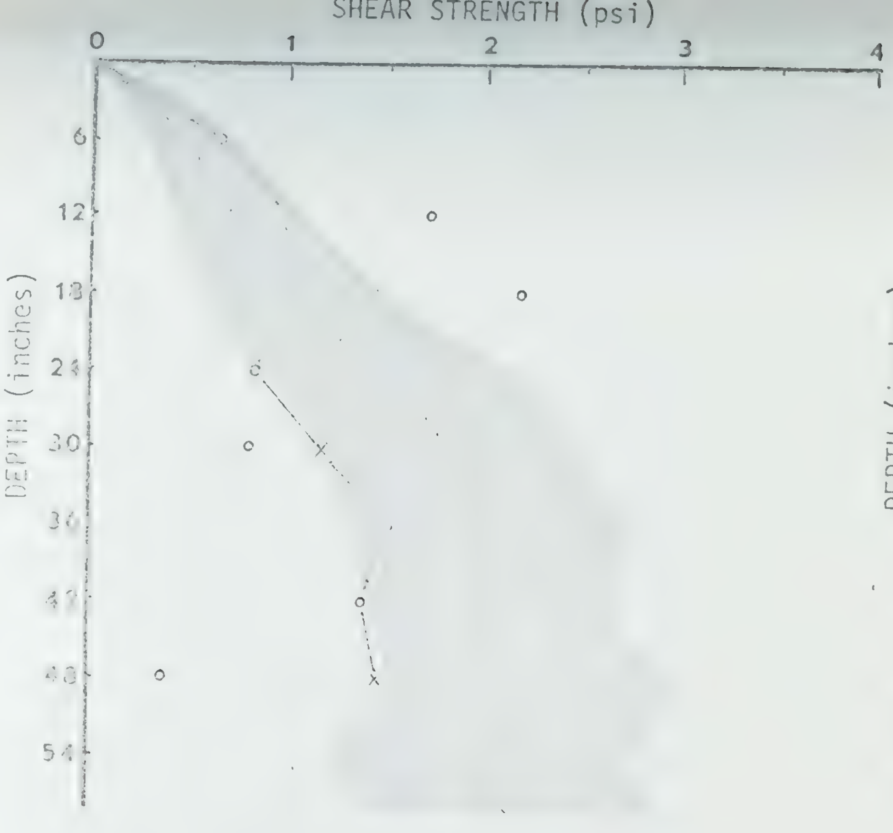


CYLINDER ON END
Velocity 5.0 fps
Station 14

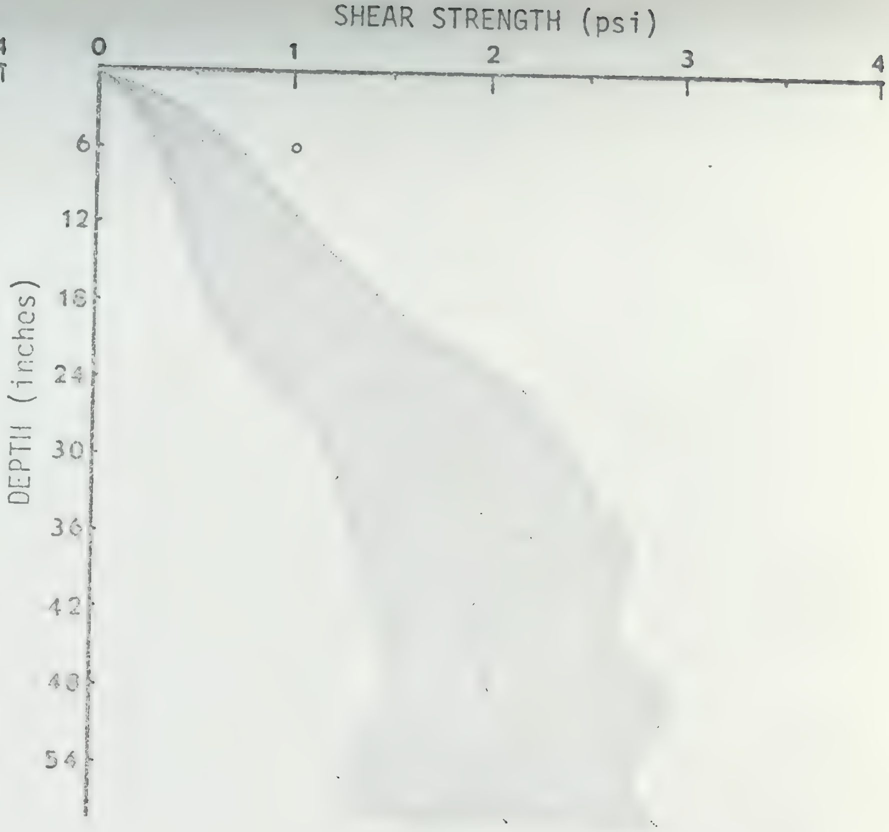


CYLINDER ON END
Velocity 10.0 fps
Station 16

○ observed ------ mean ——— shear strength used
× adjusted ▨ one standard deviation from mean



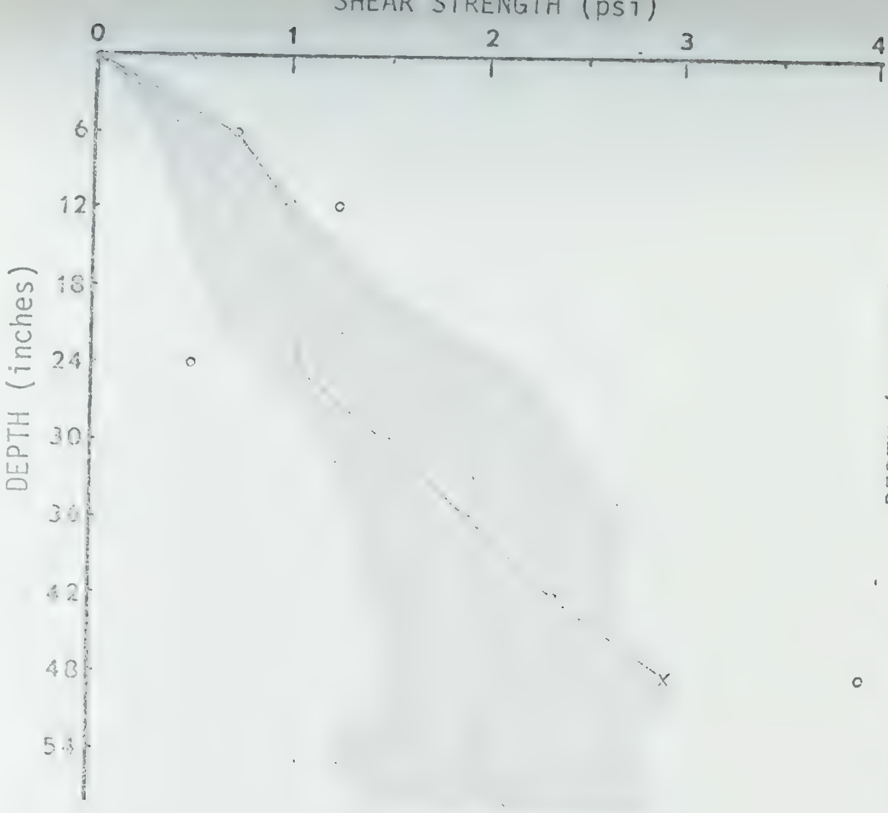
CYLINDER ON END
Velocity 15.0 fps
Station 12



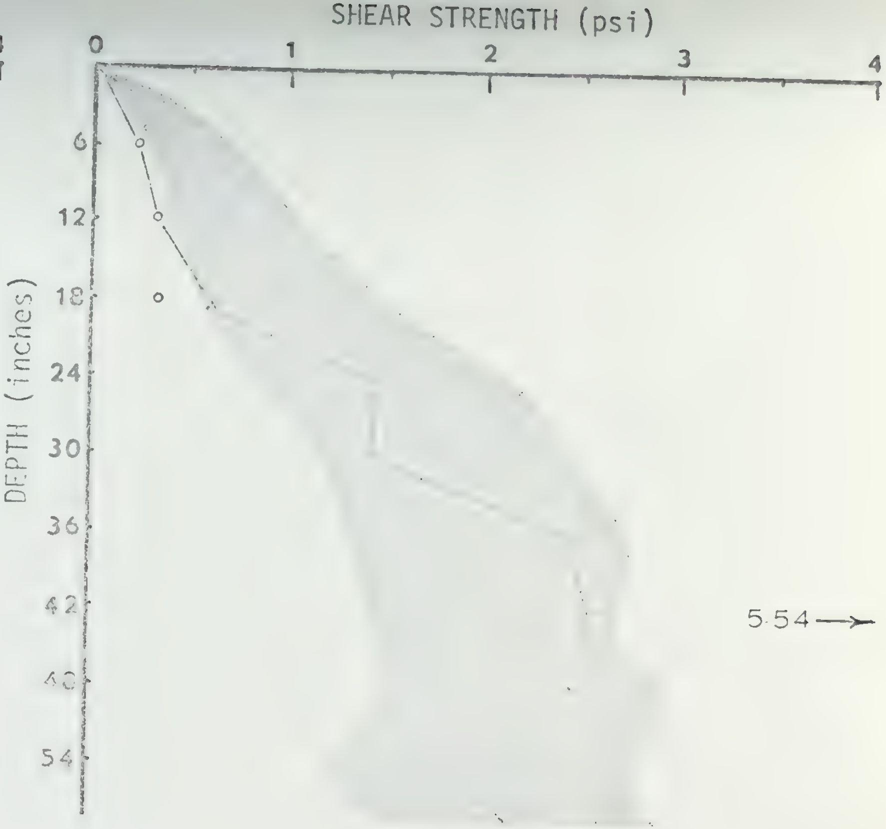
CYLINDER ON END
Velocity 15.0 fps
Station 21

○ observed
× adjusted

------ mean
——— shear strength used
▨ one standard deviation from mean

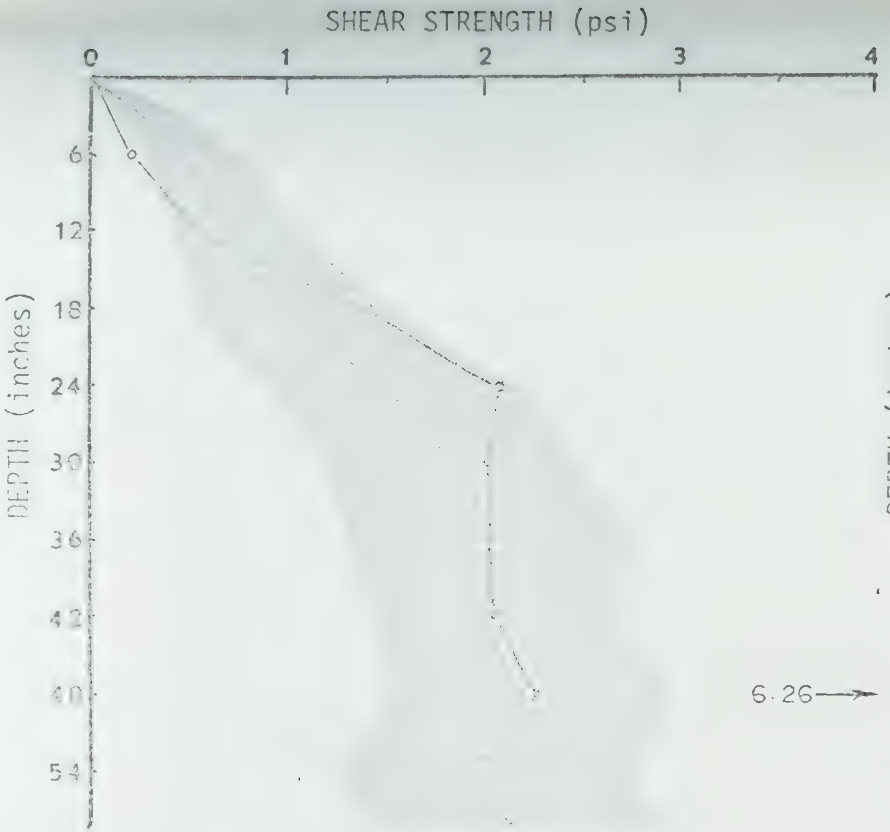


CYLINDER ON END
Velocity 20.0 fps
Station 11

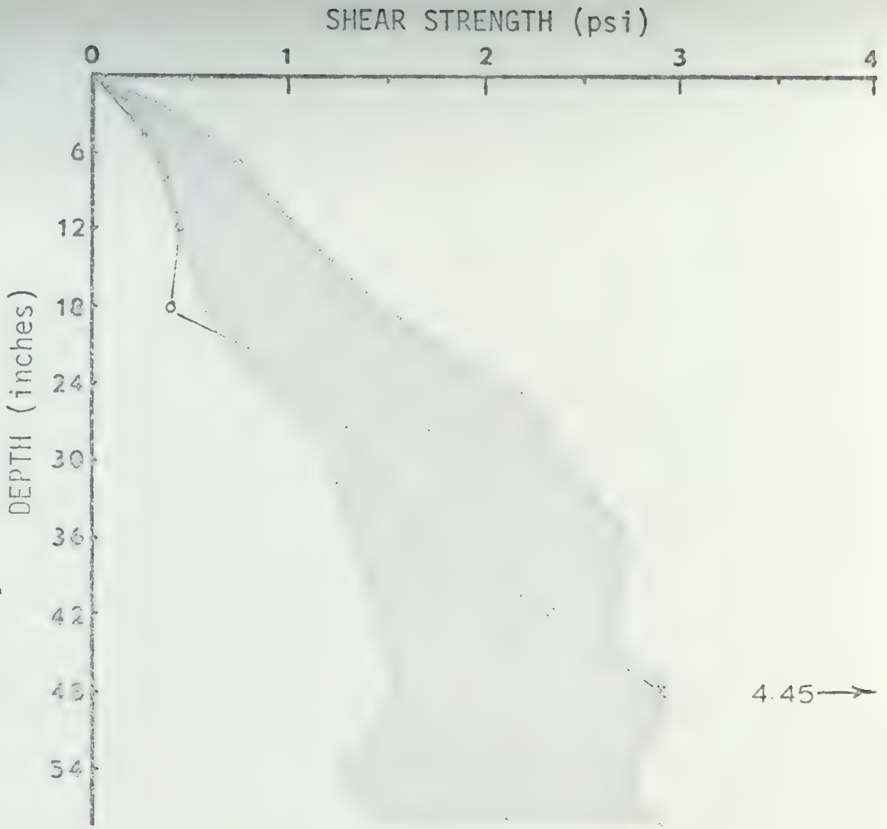


CYLINDER ON END
Velocity 5.0 fps
Station 20

○ observed
× adjusted
------ mean
——— shear strength used
▨ one standard deviation from mean

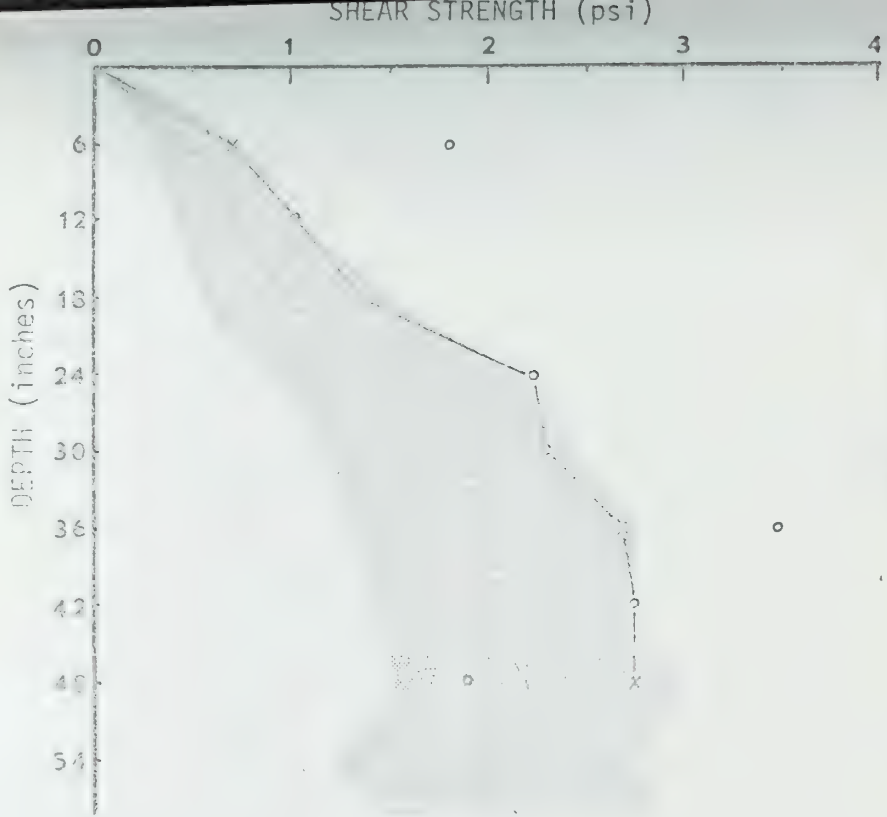


CYLINDER ON END
Velocity 10.0 fps
Station 25

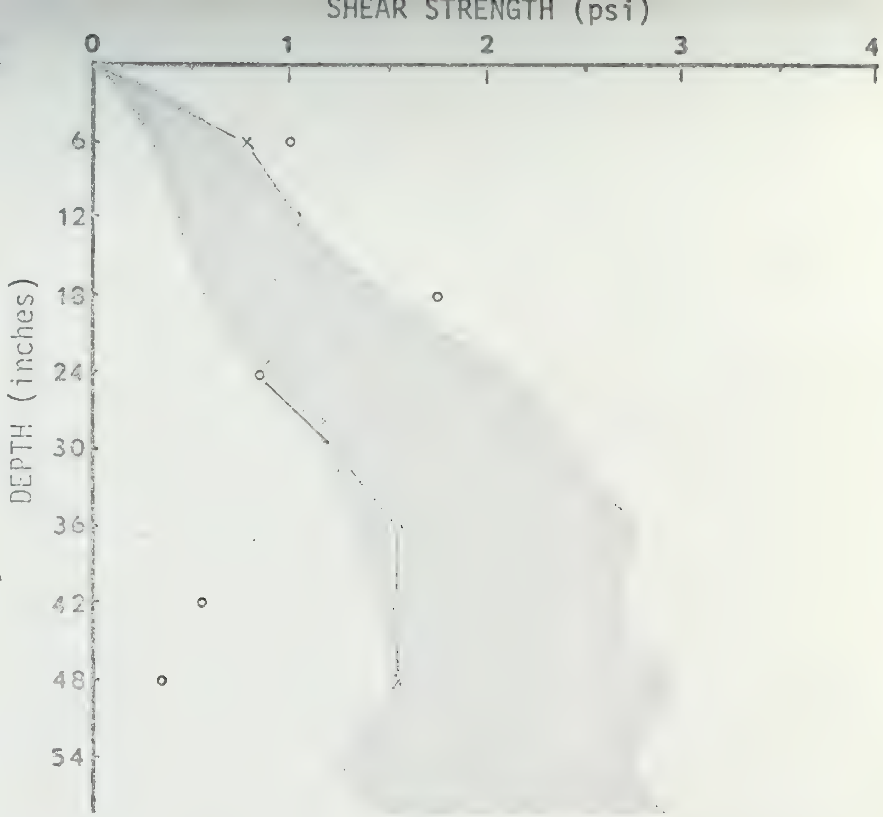


CYLINDER ON END
Velocity 15.0 fps
Station 19

∘ observed ------ mean ——— shear strength used
× adjusted ▨ one standard deviation from mean

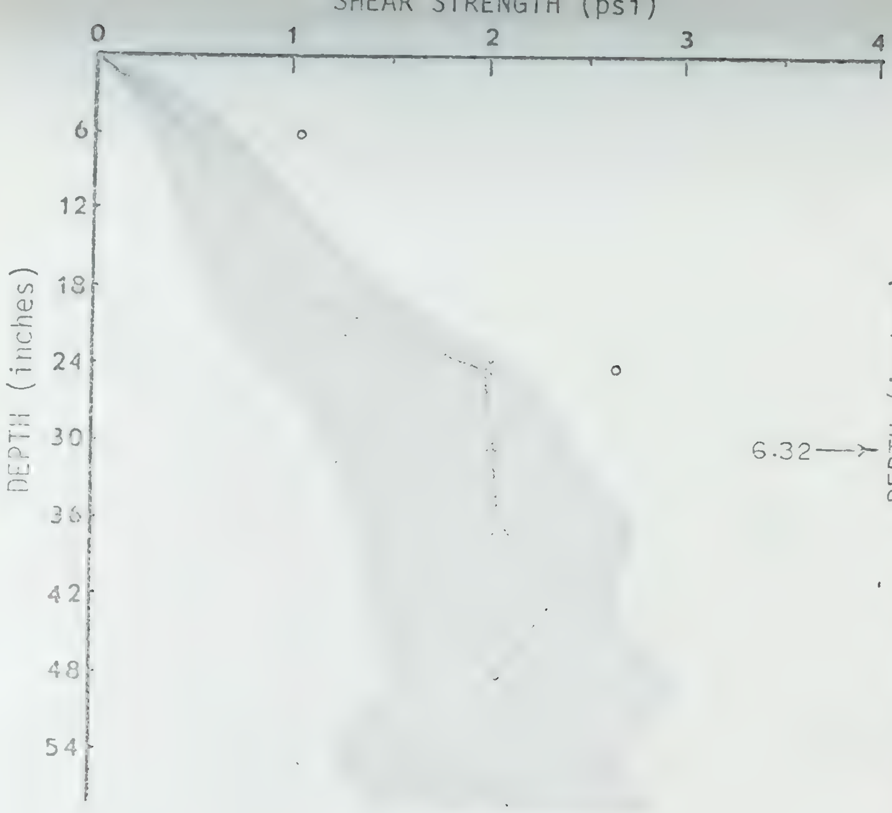


CYLINDER ON END
Velocity 20.0 fps
Station 35

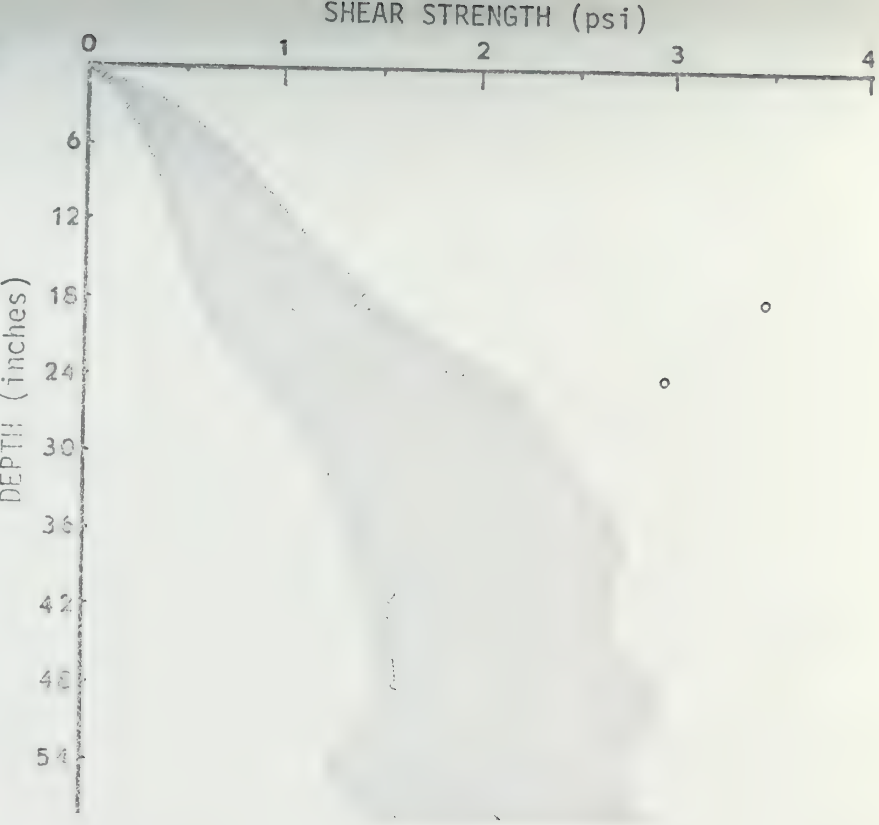


CUBE
Velocity 5.0 fps
Station -

o observed ------ mean ——— shear strength used
× adjusted ▨ one standard deviation from mean

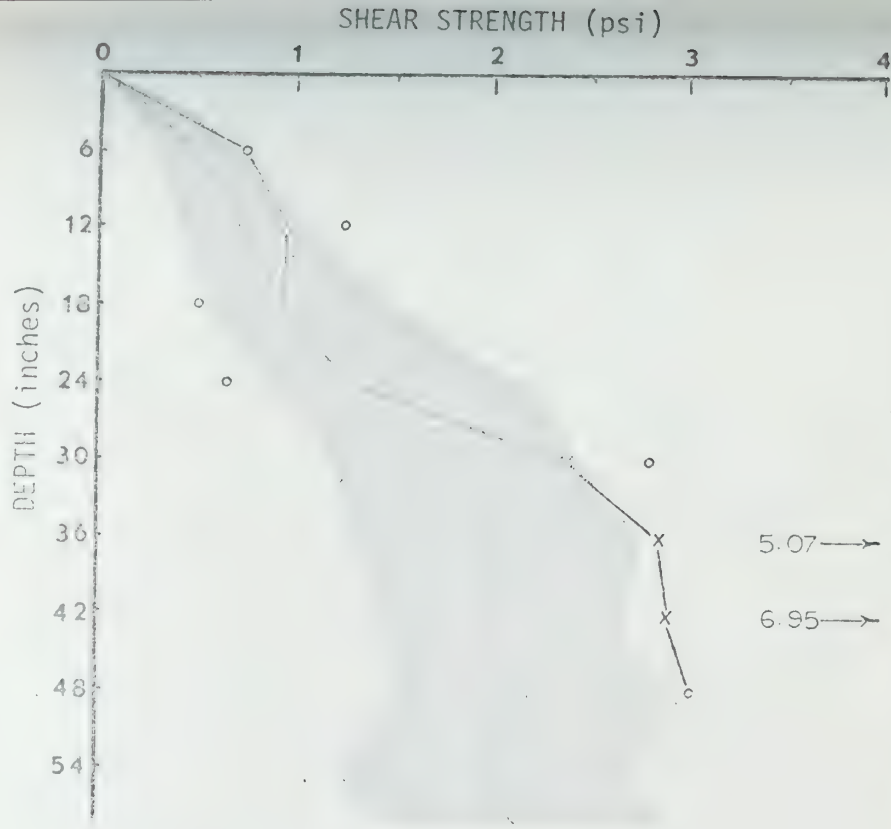


CUBE
Velocity 10.0 fps
Station -

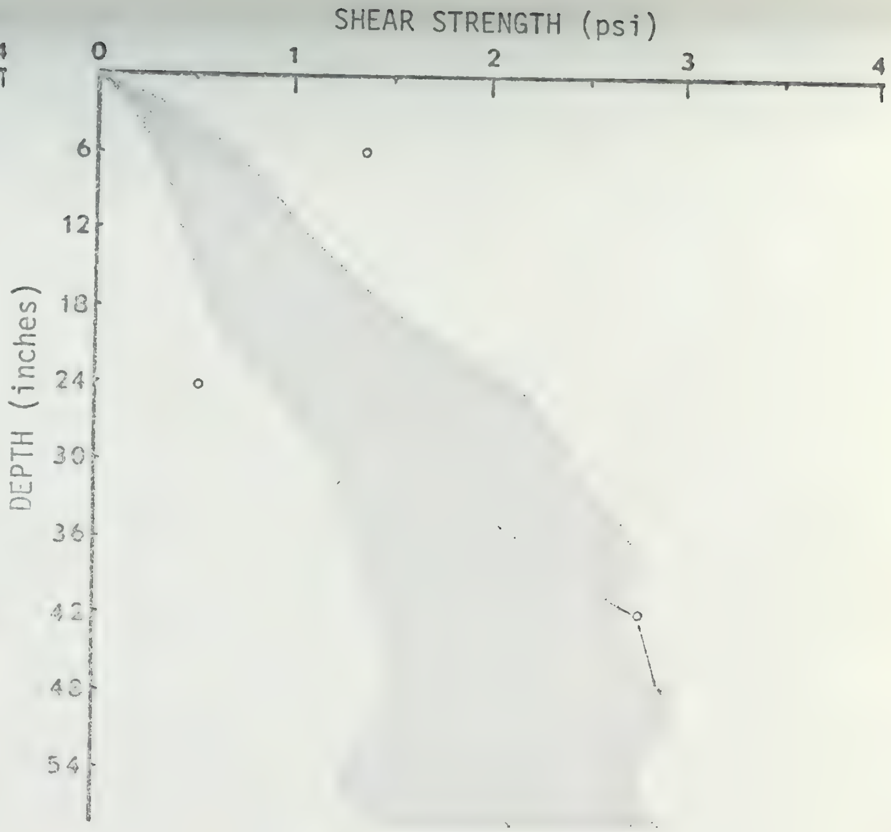


CUBE
Velocity 15.0 fps
Station -

○ observed ------ mean ——— shear strength used
× adjusted ▨ one standard deviation from mean

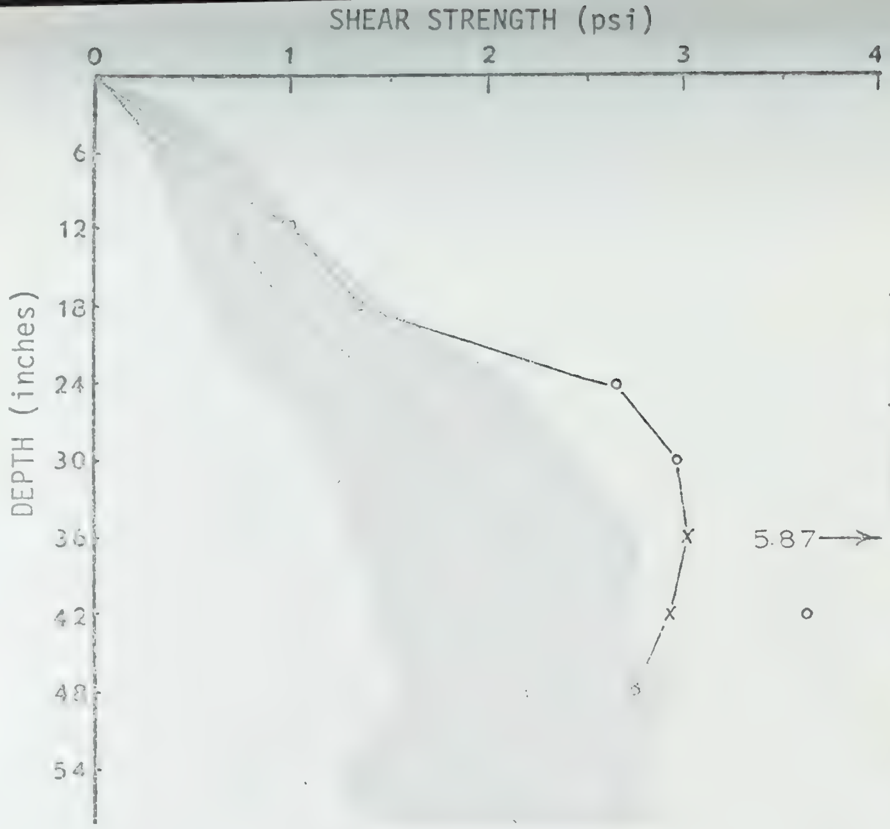


CUBE
Velocity 20.0 fps
Station -

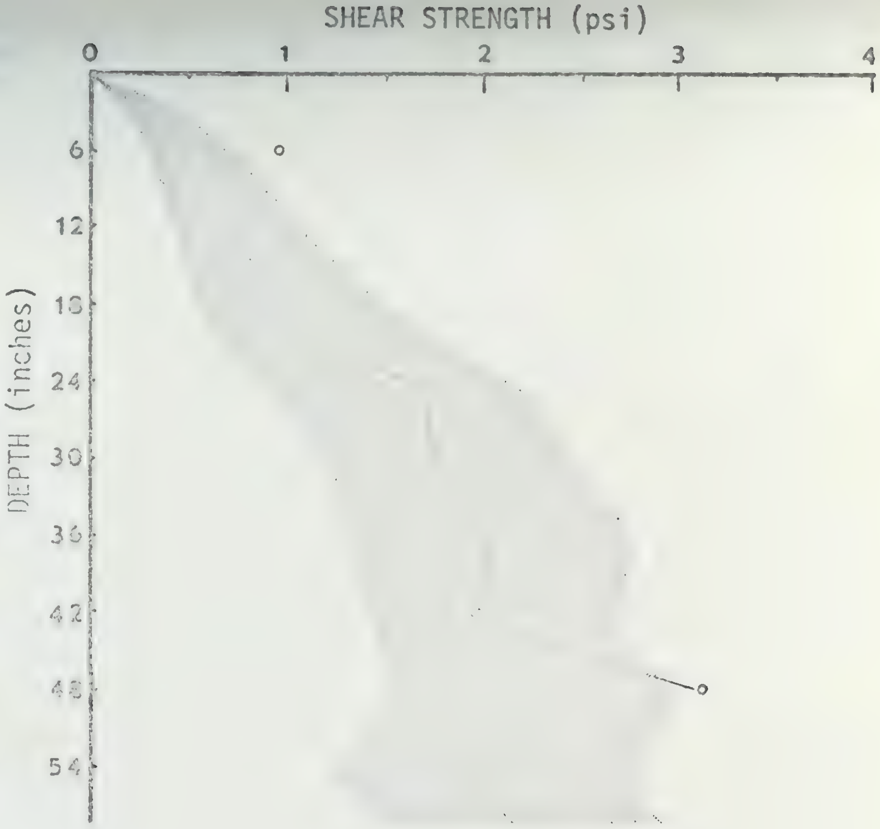


RECTANGLE
Velocity 0.0 fps
Station 24

○ observed ------ mean ——— shear strength used
× adjusted ▨ one standard deviation from mean

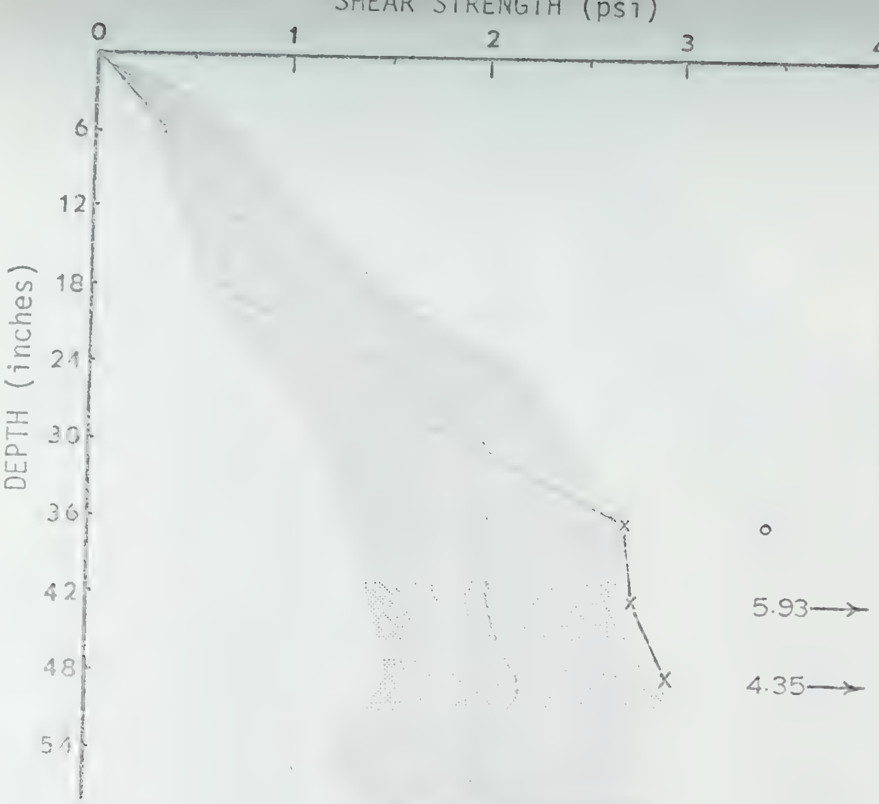


RECTANGLE
Velocity 5.0 fps
Station 13

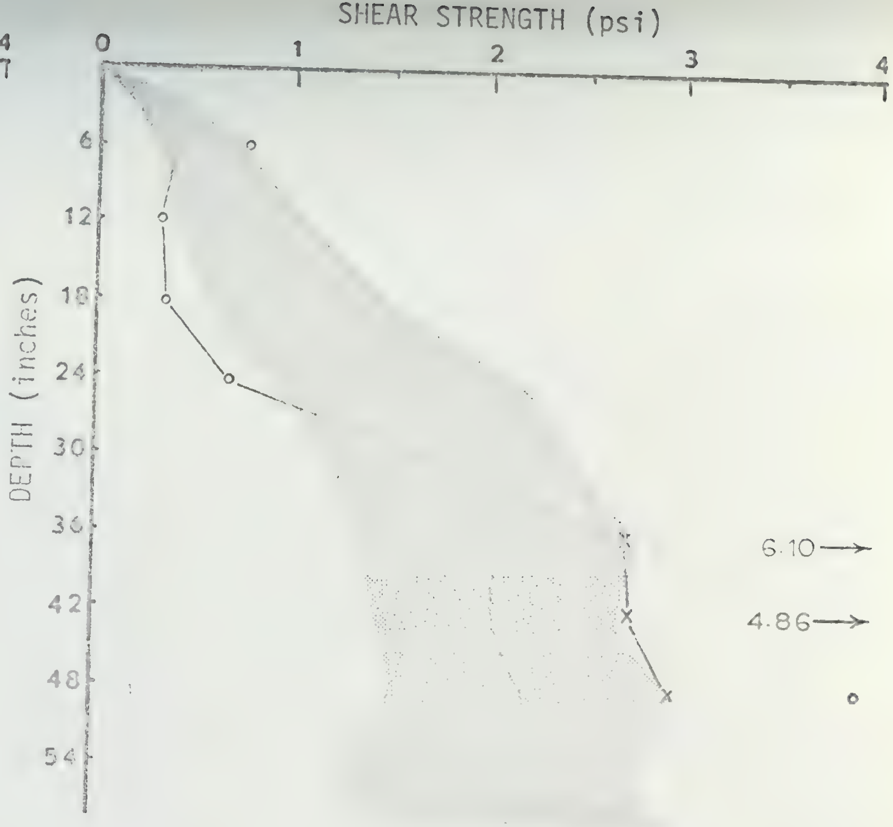


RECTANGLE
Velocity 10.0 fps
Station 11

o observed ------ mean ——— shear strength used
× adjusted ▨ one standard deviation from mean



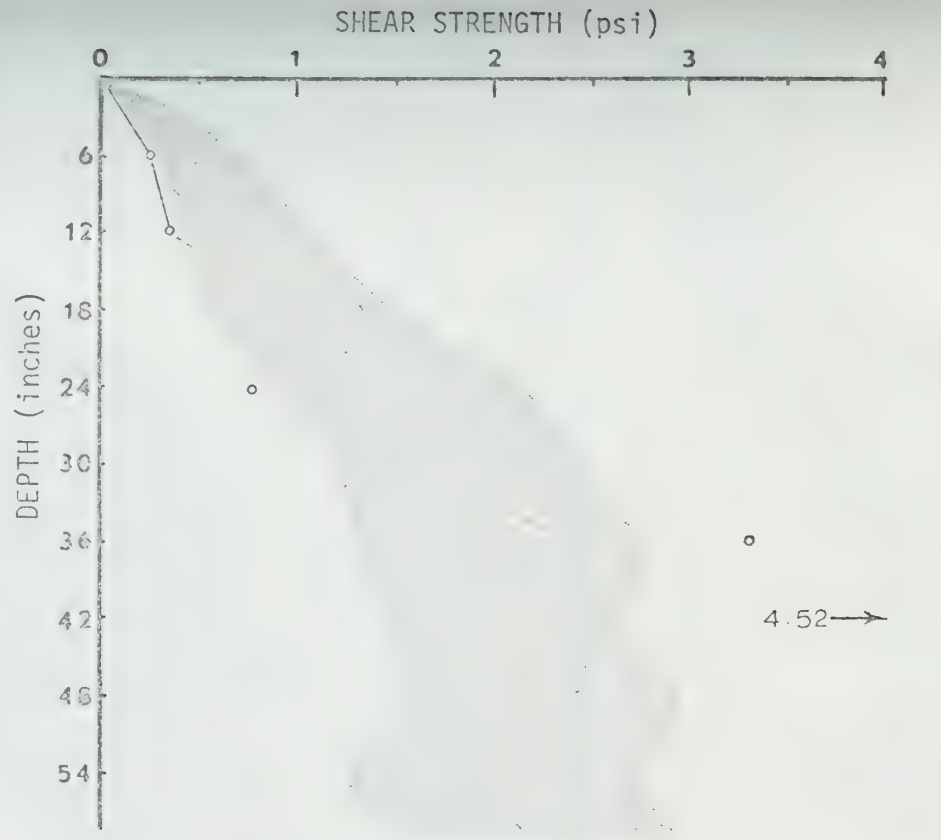
RECTANGLE
Velocity 15.0 fps
Station 17



RECTANGLE
Velocity 15.0 fps
Station 19

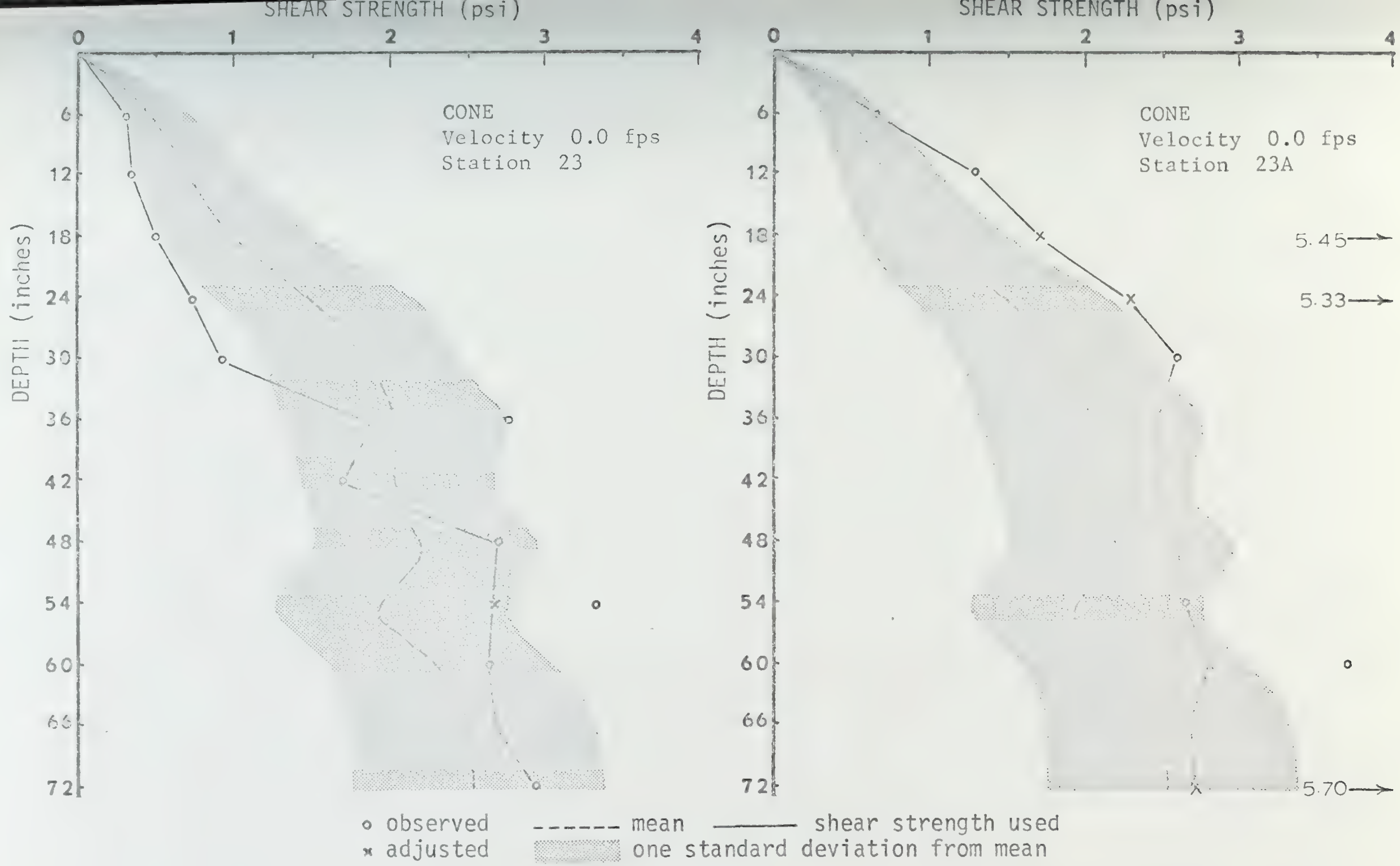
○ observed
× adjusted

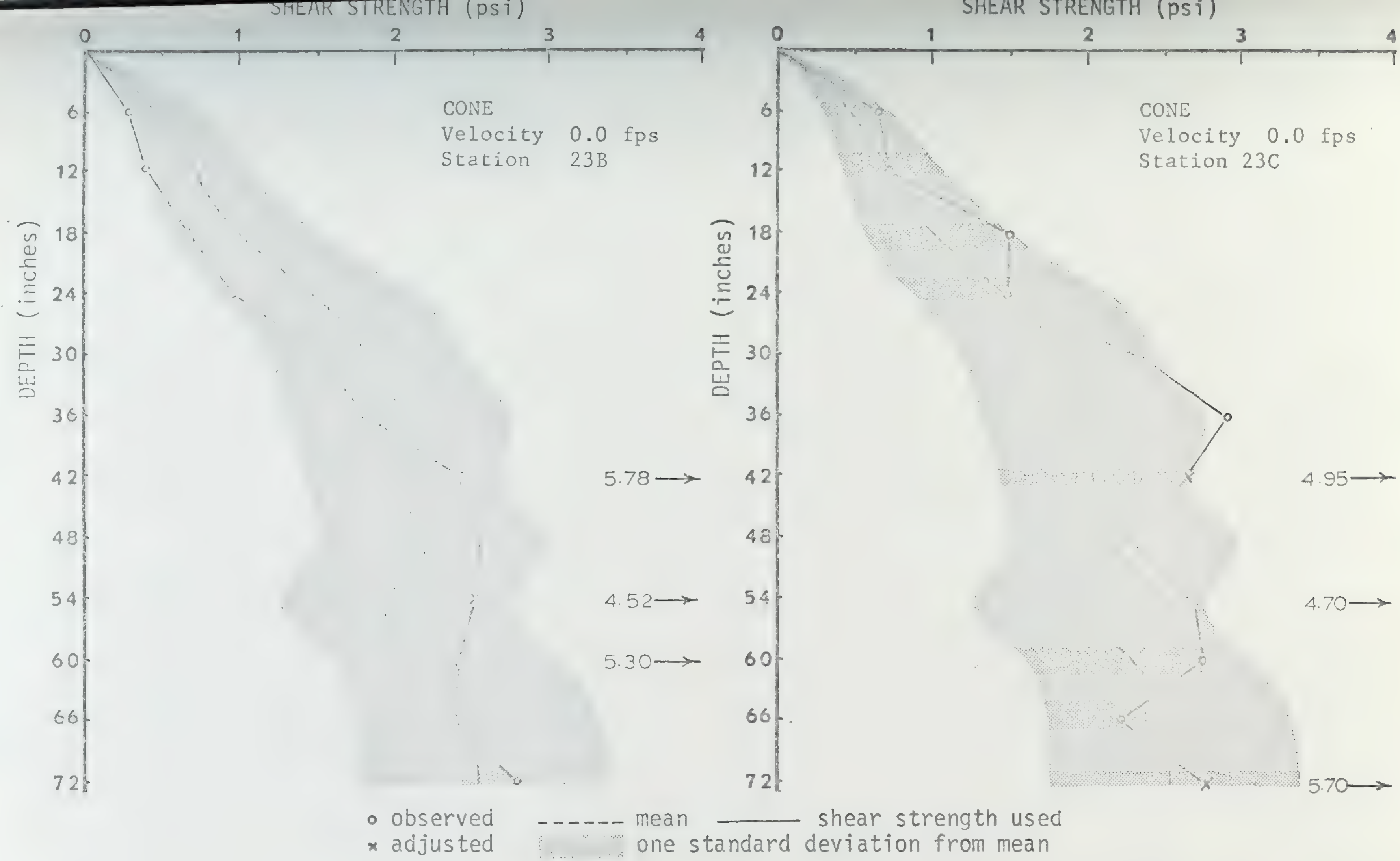
------ mean
——— shear strength used
▨ one standard deviation from mean

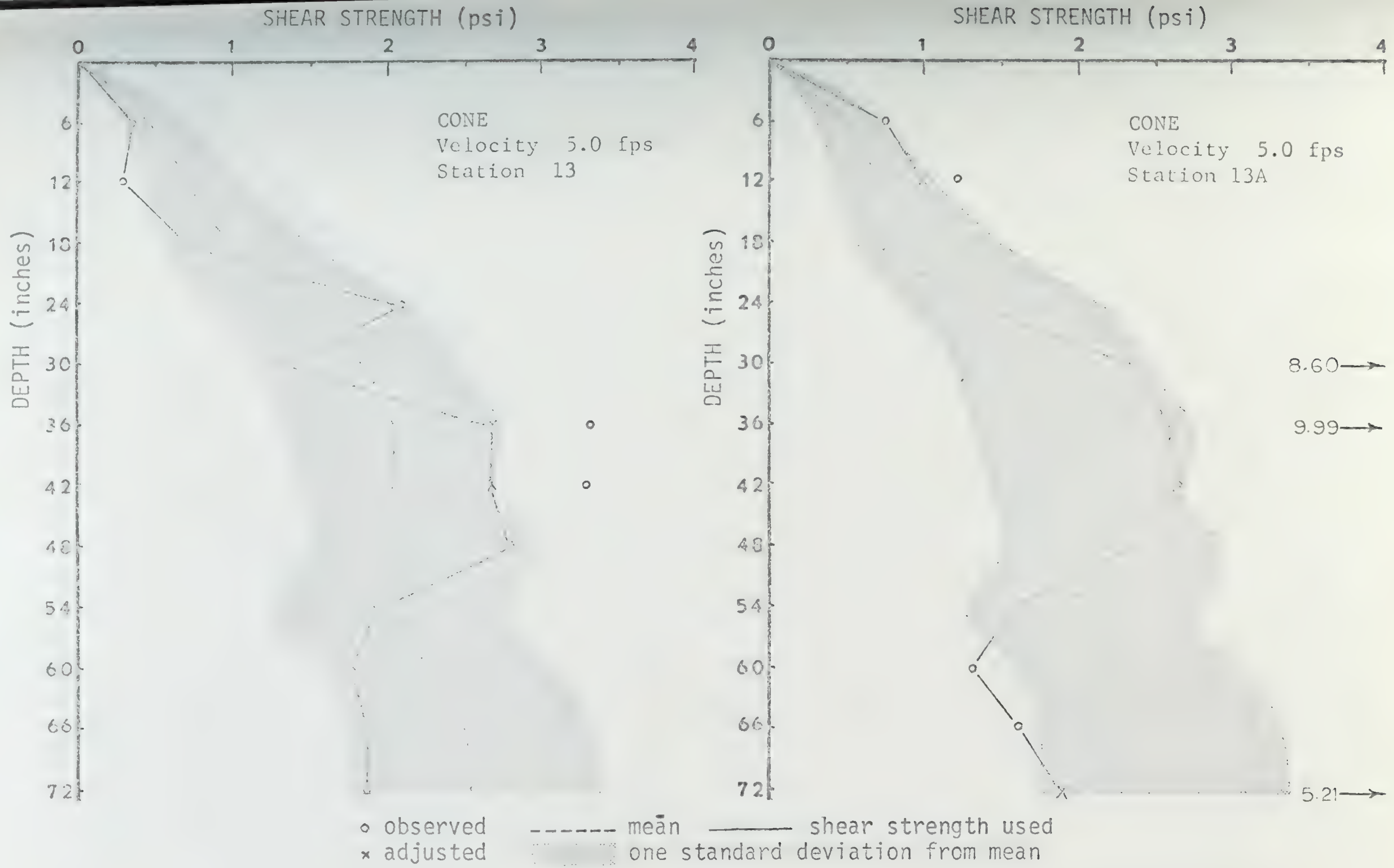


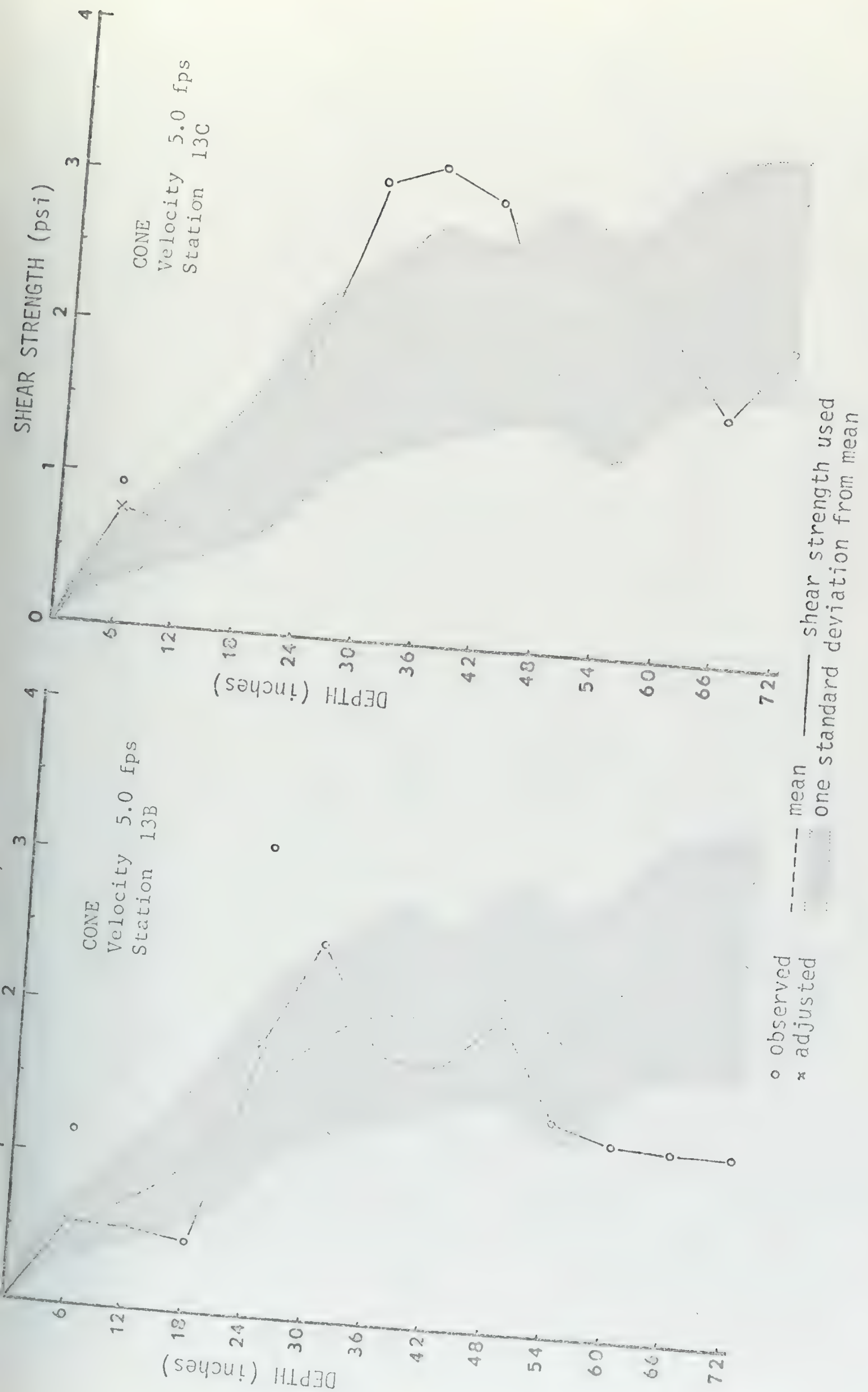
RECTANGLE
Velocity 20.0 fps
Station 18

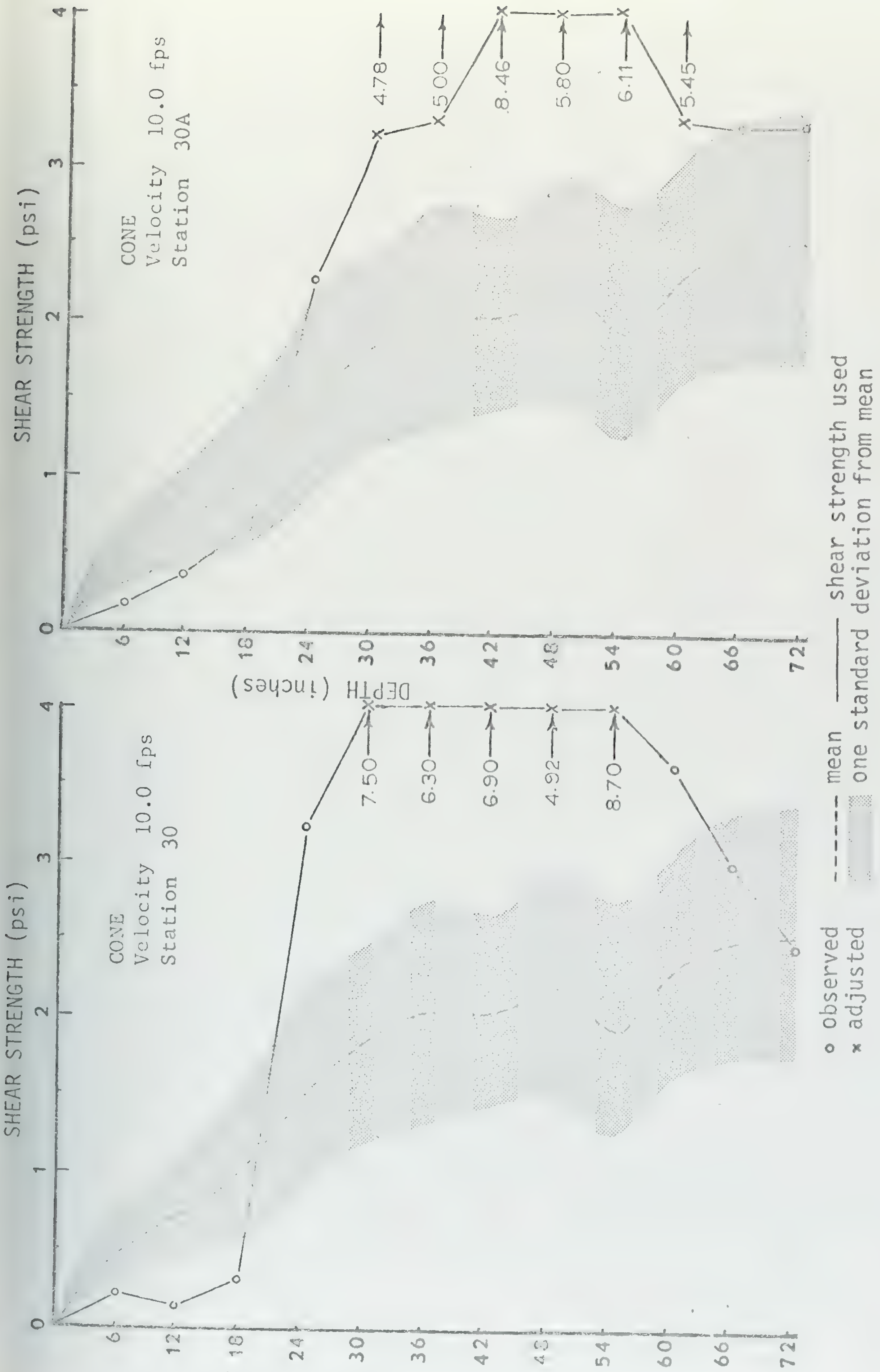
○ observed ------ mean ——— shear strength used
× adjusted ▨ one standard deviation from mean

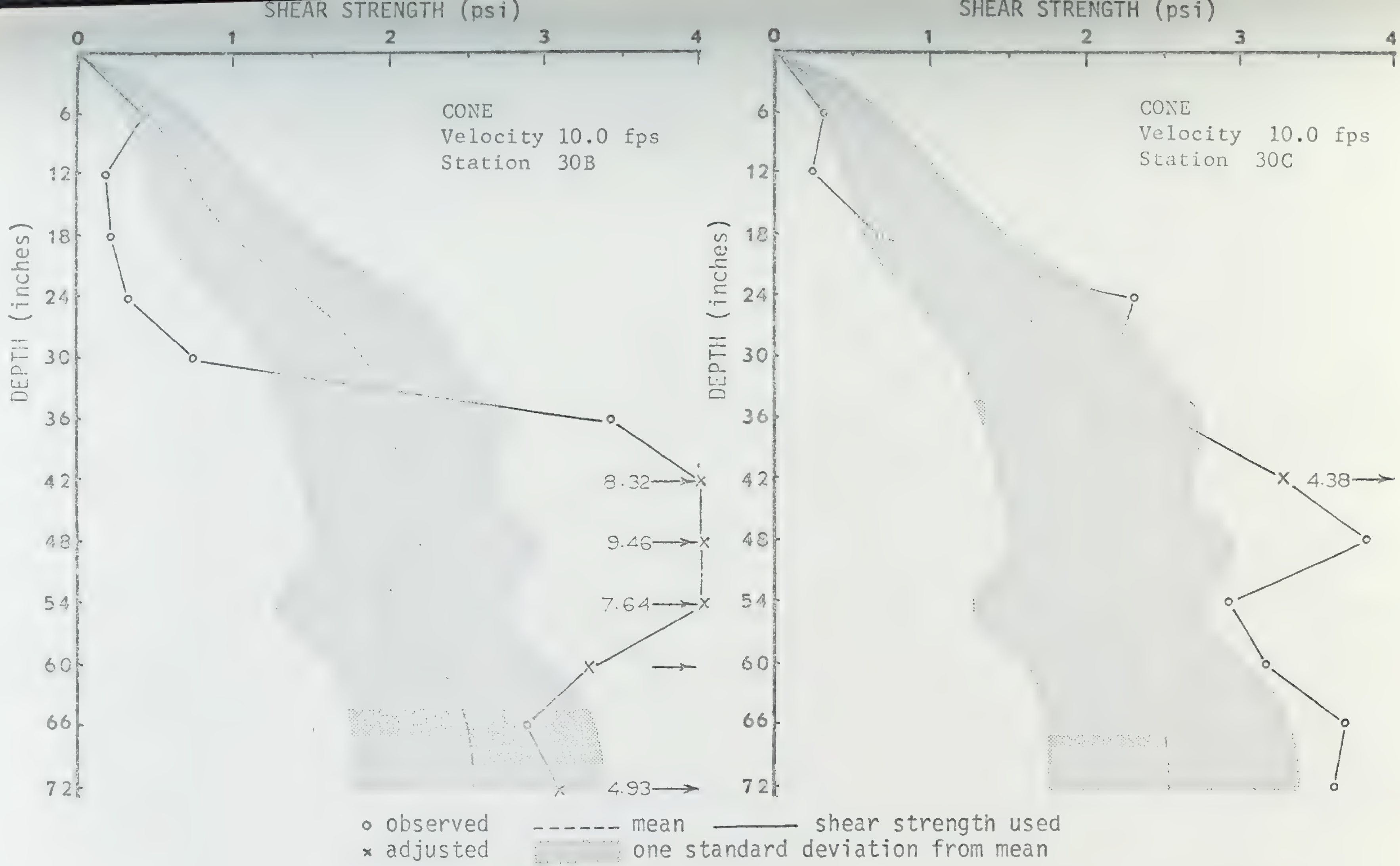

SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 0.0 fps
Station 23
SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 0.0 fps
Station 23A
5.45
5.33
5.70
o observed
× adjusted
------ mean
——— shear strength used
one standard deviation from mean

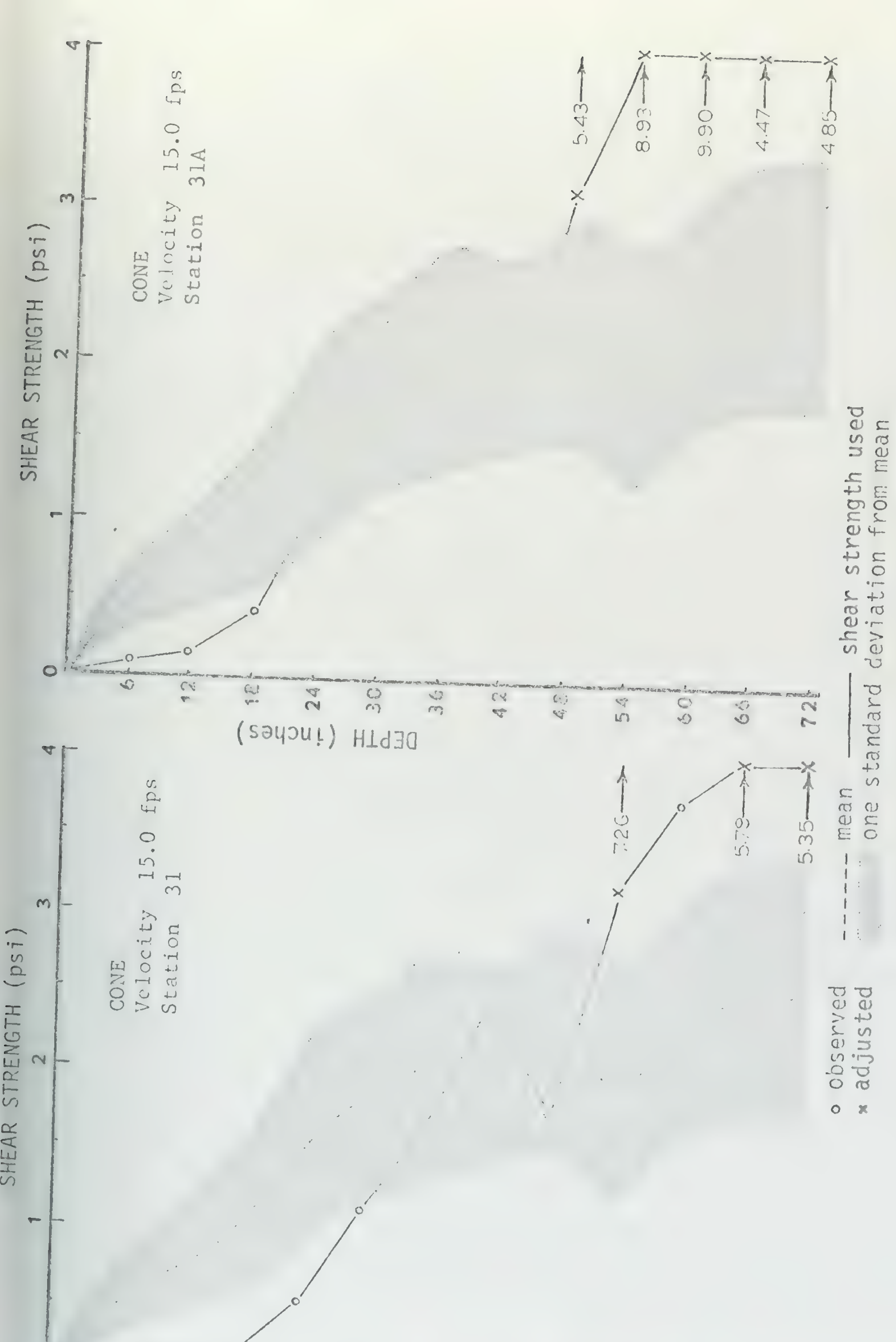

SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 0.0 fps
Station 23B
5.78
4.52
5.30
SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 0.0 fps
Station 23C
4.95
4.70
5.70
o observed
× adjusted
------ mean
one standard deviation from mean
——— shear strength used

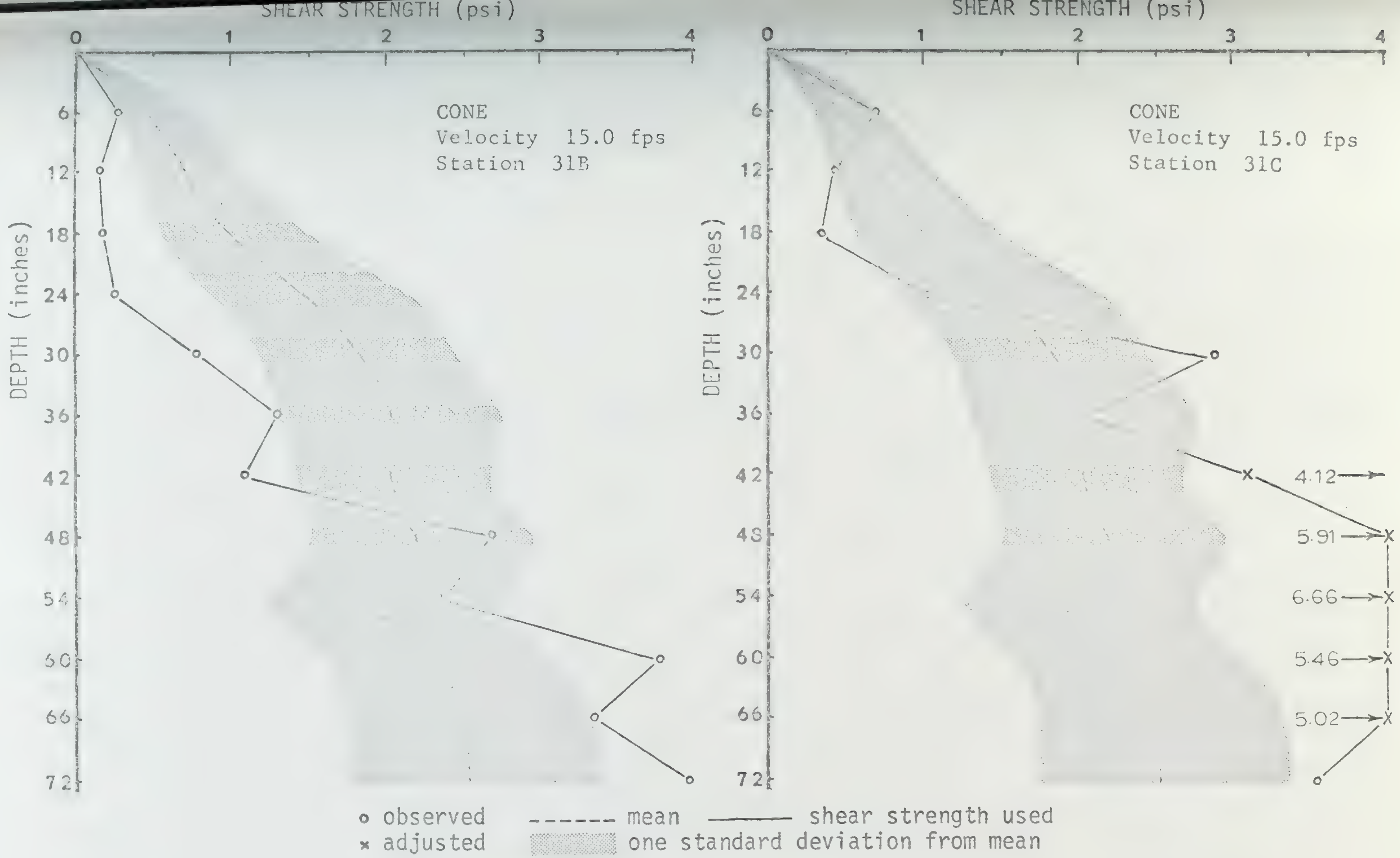

SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 5.0 fps
Station 13
SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 5.0 fps
Station 13A
8.60
9.99
5.21
o observed
× adjusted
mean
shear strength used
one standard deviation from mean

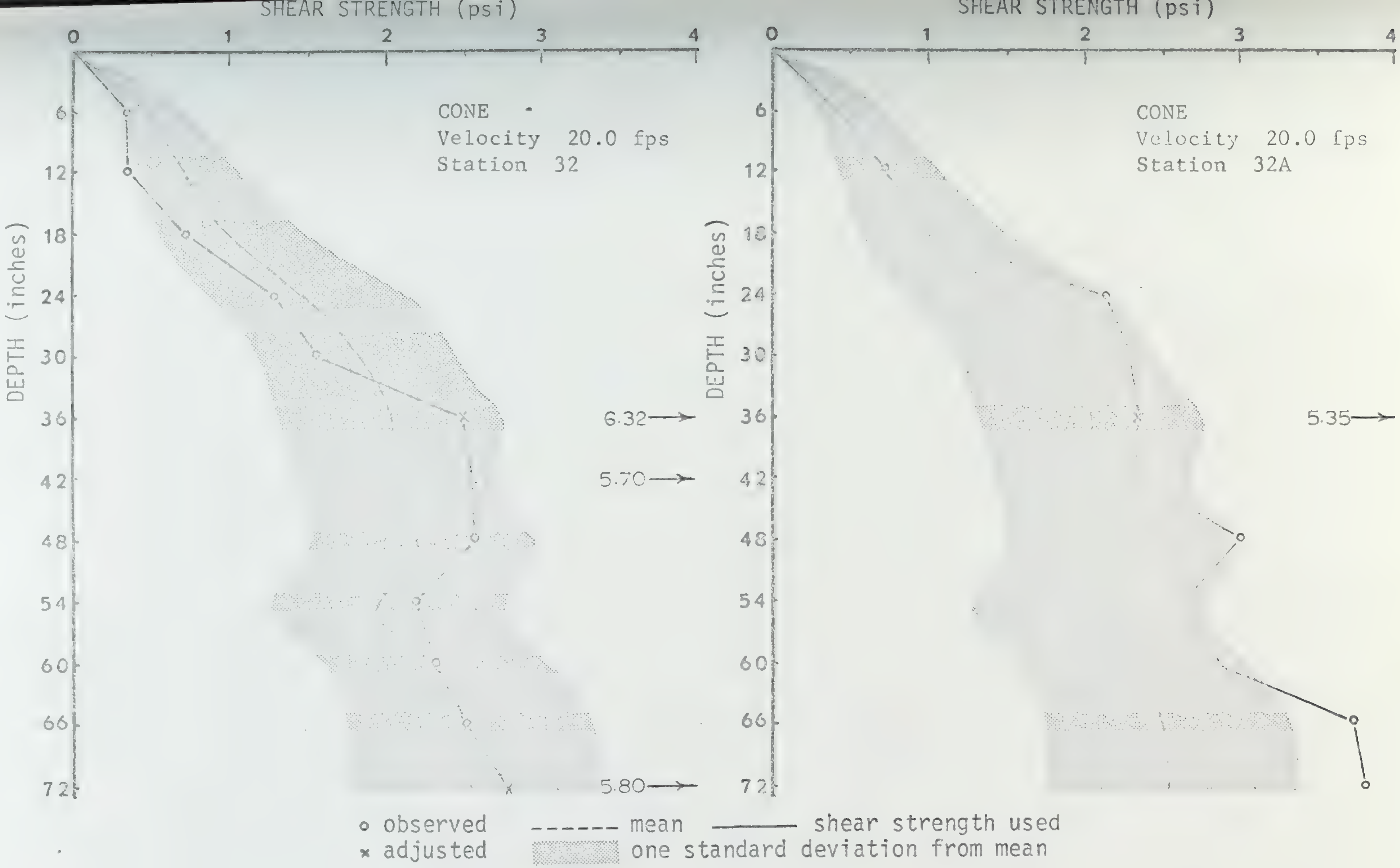

SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 5.0 fps
Station 13B
CONE
Velocity 5.0 fps
Station 13C
o observed
x adjusted
------ mean
—— shear strength used
one standard deviation from mean

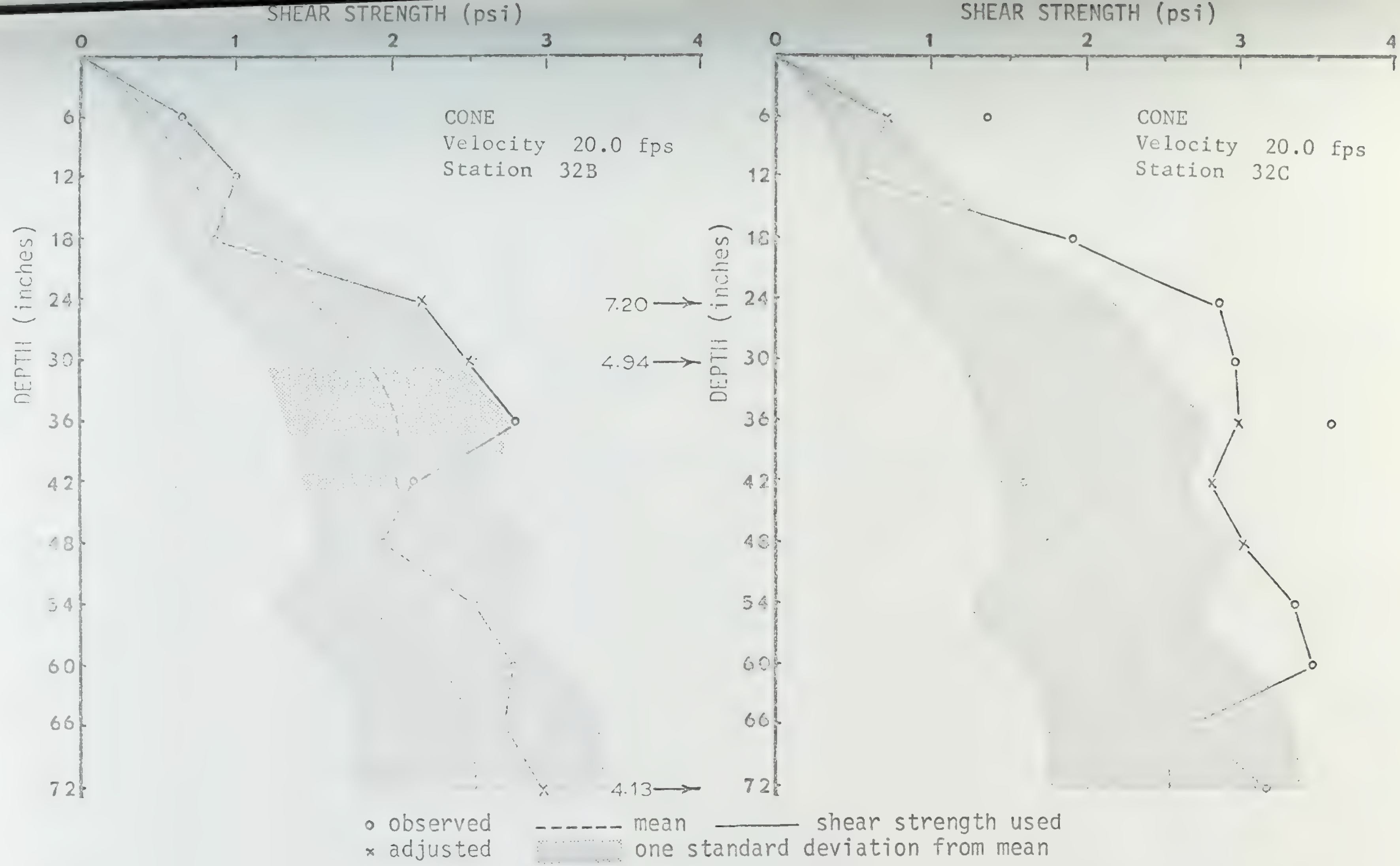

SHEAR STRENGTH (psi)
0
1
2
3
4
CONE
Velocity 10.0 fps
Station 30
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
7.50
6.30
6.90
4.92
8.70
SHEAR STRENGTH (psi)
CONE
Velocity 10.0 fps
Station 30A
4.78
5.00
8.46
5.80
6.11
5.45
o observed
x adjusted
---- mean
—— shear strength used
one standard deviation from mean


SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 10.0 fps
Station 30B
8.32
9.46
7.64
4.93
SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 10.0 fps
Station 30C
4.38
○ observed
× adjusted
------ mean
——— shear strength used
one standard deviation from mean


SHEAR STRENGTH (psi)
DEPTH (inches)
CONE
Velocity 15.0 fps
Station 31
7.26
5.79
5.35
CONE
Velocity 15.0 fps
Station 31A
5.43
8.93
9.90
4.47
4.85
0
1
2
3
4
6
12
18
24
30
36
42
48
54
60
66
72
o observed
x adjusted
------ mean
—— shear strength used
one standard deviation from mean


SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 15.0 fps
Station 31B
SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 15.0 fps
Station 31C
4.12
5.91
6.66
5.46
5.02
o observed
× adjusted
------ mean
▨ one standard deviation from mean
——— shear strength used


SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 20.0 fps
Station 32
6.32
5.70
5.80
SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 20.0 fps
Station 32A
5.35
○ observed
× adjusted
------ mean
——— shear strength used
▨ one standard deviation from mean


SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 20.0 fps
Station 32B
7.20
4.94
4.13
SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 20.0 fps
Station 32C
○ observed
× adjusted
------ mean
——— shear strength used
▨ one standard deviation from mean

APPENDIX C: COMPUTATION OF SPHERE PENETRATION

```
C DYNAMIC PENETRATION OF AN OBJECT INTO THE OCEAN BOTTOM
C UNITS FEET/POUNDS/SLUGS/SECONDS/
C
C DX       INCREMENT SIZE
C
C BWD      BULK WET DENSITY OF SEDIMENT
C
C BMASS    OBJECT MASS
C
C AMASS( ) ADDED MASS PLUS MASS OF DISPLACED SEDIMENT AT SECTION ( )
C
C DMASS( )CHANGE IN AMASS OVER SECTION INDICATED BY SUBSCRIPT
C
C AREA( ) PROJECTED AREA FOR SECTION ( )
C
C CNC      BEARING CAPACITY COEFFICIENT
C
C VOL( )   VOLUME OF SECTION ( )
C
C CFOOT    BEARING CAPACITY CONSTANT DEPENDS ON SHAPE OF AREA
C
C XXX      DEPTH OF PENETRATION
C
C SVOL( ) SUM OF VOLUMES TO SECTION INDICATED
C
C V( )     VELOCITY OF OBJECT AT SECTION ( )
C
C WS( )    WORK DONE BY SEDIMENT IN SECTION ( )
C
C WT       WEIGHT OF OBJECT
C
C G        ACCELERATION OF GRAVITY
C
C SPS      SHEAR STRENGTH OF SEDIMENT
C
C RAD      RADIUS
C
C WDRAG    WORK DONE BY DRAG FORCES
C
C WB( )    WORK DONE BY BUOYANCY WHEN SUBMERGING TO SECTION ( )
C
C WBSUB( )WORK DONE BY SUBMERGED SECTION ( )
C
C US( )    WORK TO SUBMERGE SECTION ( )
```

```
C
C SUMSUB( )WORK DONE BY SUBMERGED SECTIONS TO SECTION( )
C
C E( )     KINETIC ENERGY OR BODY AT SECTION( )
C
C
      DIMENSION AREA(100),VOL(100),AMASS(100),DMASS(100),SVOL(100),WS(10
     20),WB(100),WBSUB(50),US(50),SUMSUB(50),E(100),V(100)
C     RESET DIMENSIONS FOR LARGE OBJECTS
      DATA PI/3.141593/,G/32.1725/,AREA/100*0.0/,VOL/100*0.0/,AMASS/100*
     20.0/,DMASS/100*0.0/,SVOL/100*0.0/,WS/100*0.0/,WB/100*0.0/,WBSUB/50
     3*0.0/,US/50*0.0/,SUMSUB/50*0.0/,E/100*0.0/,V/100*0.0/
C
C
C
C     INPUT DATA ON OBJECT
C     OBJECT SPHERE
      RAD=1.192
      WT=561.
      BWD=97.402/G
      CFOOT=1.3
      CNC=5.7
C     COHESION OR SHEAR STRENGTH IN PSI EQUALS .3 FOR PROGRAM CHECKOUT
      COH=43.2
C     FOR A SPHERE USE A COEFFICIENT OF DRAG EQUAL TO 0.3
      CD=0.3
C
C     SET INCREMENT
      DX=.05
C
C
C
C     CALCULATE THE SECTION PROPERTIES,AVERAGE PROJECTED AREA,VOLUME
C     FIND AREA AT MIDPOINT OF EACH SECTION
C     Y=DISTANCE ABOVE BOTTOM OF SPHERE
      Y=DX/2.
      YMAK=2*RAD
      Z=RAD/DX
      N=Z+1.
C     THE ONE ACCOUNTS FOR INTEGER TRUNCATION IN THIS PROBLEM
      AREA(1)=PI*(RAD**2-(RAD-Y)**2)
      DO 100 I=2,N
      AREA(I)=PI*(RAD**2-(RAD-(I-1)*DX-Y)**2)
  100 CONTINUE
C
C     FOR THIS ANALYSIS AFTER THE AREA HAS BECOME A MAXIMUM IT WILL BE
C     CONSTANT FOR THE REMAINING PENETRATION THEREFORE SET SUCCEEDING
C     AREAS AS FOLLOWS
```

```
      DO 200 I=N,100
      AREA(I)=AREA(N)
  200 CONTINUE
C
C     COMPUTE THE VOLUME OF EACH SECTION
C     VOLUME EQUALS AVERAGE AREA TIMES SECTION HEIGHT
      DO 300 I=1,100
      VOL(I)=AREA(I)*DX
  300 CONTINUE
C
C     CHECK VOLUME CALCULATIONS
      HAFVOL=(2./3.)*PI*RAD**3
      CVOL=VOL(1)
      DO 350 I=2,N
      CVOL=CVOL+VOL(I)
  350 CONTINUE
C
      ERROR=CVOL-HAFVOL
C     PRINT,CVOL,HAFVOL,ERROR
C
C
C
C     CALCULATE ADDED MASS, DISPLACED MASS AND CHANGE IN ADDED MASS AND
C     DISPLACED MASS FROM SECTION TO SECTION
C     APPROXIMATE BY USING ONE HALF ON AN ELIPTICAL FORM. AMASS BECOMES
C     CONSTANT WHEN MAX AREA HAS BEEN REACHED
C
      SUMVOL=0.0
      K=N+1
C     INTEGERS TRUNCATE SO THERE IS AN APPROXIMATION HERE IN THE NUMBER
C     OF ITERATIONS TAKEN
      DO 400 I=2,K
C     SEE PAGE 421 OF SAUNDERS FOR FORMULAS BELOW
      B=(I-1)*DX-Y
      A=RAD**2-(RAD-B)**2
      AS=SQRT(A)
      EE=1-(B**2)/A
      D=SQRT(EE)
C
C     NOW ADDED MASS,DESIGNATE SOME NEW VARIABLES
      SI=ARSIN(D)
      SQRE=SQRT(1-D**2)
C     ADD DISPLACED VOL AT THE SAME TIME
      AMASS(I-1)=BWD*((2./3.)*PI*AS**3*((D-SI*SQRE)/(SI-D*SQRE)))
C
C     SUM THE VOLUMES BEFORE ADDING
C
      SUMVOL=SUMVOL+VOL(I-1)
```

```
C     SUMVOL AT END OF DO LOOP SHOULD EQUAL HAFVOL
C
      AMASS(I-1)=AMASS(I-1)+BWD*SUMVOL
  400 CONTINUE
C
C     CHECK ADDED MASS BY COMPARING LAST INCREMENT TO ONE HALF SPHERE
C
      HAMAS=BWD*(PI*RAD**3)
      ERROR=HAMAS-AMASS(N)
      PRINT,HAMAS,AMASS(N),ERROR
C
C
C     AMASS REMAINS THE SAME AFTER MAX AREA
C
      DO 450 I=N,100
      AMASS(I)=AMASS(N)
  450 CONTINUE
C
C     COMPUTE CHANGE IN AMASS FROM SECTION TO SECTION
      DMASS(1)=0.0
      DO 500 I=2,N
      DMASS(I)=AMASS(I)-AMASS(I-1)
  500 CONTINUE
C
C     SUM DMASS, IT SHOULD BE CLOSE TO AMASS(N)
C
      CDMASS=DMASS(1)
      DO 550 I=2,N
      CDMASS=CDMASS+DMASS(I)
  550 CONTINUE
      PRINT,CDMASS,AMASS(N)
C
C
C
C
C     CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C     PER SECTION IF THE SHEAR STRENGTH IS CONSTANT FOR PROGRAM CHECK
C     ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X COHESIONX DX
      CT=CFOOT*CNC
      DO 600 I=1,100
      WS(I)=CT*COH*AREA(I)*DX
  600 CONTINUE
C
C
C
C     CALCULATE WORK DONE BY BUOYANCY
C
      GAMMA=BWD*G
      WB(1)=(GAMMA*AREA(1)*DX**2)/2.
      SUMSUB(1)=2.0*WB(1)
```

```
      DO 700 I=2,N
C
C     WORK TO SUBMERGE SECTION
      US(I)=(GAMMA*AREA(I)*DX**2)/2.
C
C     WORK TO CONTINUE SECTION AFTER SUBMERGING
      WBSUB(I)=2.0*US(I)
C
C     TOTAL WORK OF THE SUBMERGED SECTIONS
      SUMSUB(I)=SUMSUB(I-1)+WBSUB(I)
C
C     TOTAL WORK DONE SUBMERGING SECTION PLUS THOSE ALREADY SUBMERGED
      WB(I)=US(I)+SUMSUB(I-1)
  700 CONTINUE
C
C     AFTER ALL SECTIONS ARE SUBMERGED WORK BECOMES CONSTANT EQUAL TO
C     SUMSUB(N) PLUS WBSUB(N) FOR EACH FURTHUR INCREMENT
C
      DO 760 I=N,100
      WB(I)=SUMSUB(N)+(I-(N-1))*WBSUB(N)
  760 CONTINUE
C
C     CHECK WORK TO SUBMERGE
      CWB=WB(1)
      DO 800 I=2,N
      CWB=CWB+WB(I)
  800 CONTINUE
      PRINT,CWB
C
C
C     ACTUAL WORK BY INTEGRATION IS
C
      X=N*DX
      AWB=(GAMMA*PI/3.)*(RAD*X**3-X**4/4.)
      PRINT,AWB
C
C
C
C
C
C
C     PROGRAM TO COMPUTE PENETRATION DEPTH FOLLOWS
C
C
C     BE ABLE TO DO NNN DIFFERENT VELOCITIES AND SHEAR STRENGTHS
      READ(5,2050) NNN
      WRITE(6,2060)NNN
C
      DO 1000 J=1,NNN
      WRITE(6,2200) RAD,WT,BWD,CD
C
C     READ IN THE VELOCITIES AND SHEAR STRENGTHS
```

```
      READ(5,2100) VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40
      WRITE(6,2300)VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40
      WRITE(6,2500)
C
C     CALCULATE ORIGINAL ENERGY OF BODY AT INTERFACE
      BMASS=WT/G
      E(1)=BMASS*VO**2/2.
C
C     CALCULATE POTENTIAL ENERGY FOR EACH INCREMENT
      FP=WT*DX
C
C
C
C     COMPUTE SLOPE OF SHEAR STRENGTH VARIATIONS
      SLOPE1=SS05/.5
      BINT1=0.0
      SLOPE2=(SS10-SS05)/.5
      BINT2=-SLOPE2*.5+SS05
      SLOPE3=(SS105-SS10)/.5
      BINT3=-SLOPE3*1.+SS10
      SLOPE4=(SS20-SS105)/.5
      BINT4=-SLOPE4*1.5+SS105
      SLOPE5=(SS205-SS20)/.5
      BINT5=-SLOPE5*2.0+SS20
      SLOPE6=(SS30-SS205)/.5
      BINT6=-SLOPE6*2.5+SS205
      SLOPE7=(SS305-SS30)/.5
      BINT7=-SLOPE7*3.+SS30
      SLOPE8=(SS40-SS305)/.5
      BINT8=-SLOPE8*3.5+SS305
C
C     VELOCITY OF SEDIMENT AT INTERFACE IS ALWAYS 0 AT INSTANT OF IMPACT
      V(1)=0.0
      DO 2000 I=1,100
C     SECTION TO COMPUTE SHEAR STRENGTH
C     NOTE THAT THE SHEAR STRENGTH IS COMPUTED IN INCHES THEN CONVERTED
C     TO POUNDS PER SQUARE FOOT FOR THE CALCULATION
C
C     FOR THE SPHERE TAKE THE DEPTH FOR SHEAR STRENGTH TO BE THE PENETRA
C     TION DEPTH MINUS ONE HALF THE PENETRATION DEPTH UP TO THE MAX RAD
      DEPTH=I*DX-Y-(I*DX-Y)/2.
C     WHEN THE MAX RAD IS REACHED THE DEPTH EQUALS PENETRATION DEPTH
C     MINUS ONE HALF THE RADIUS
      IF((I*DX-Y).GT.RAD) DEPTH=I*DX-Y-RAD/2.
C     CONVERT THE DEPTH TO INCHES FOR EASY COMPARISON WITH  DATA
      DEPTHI=DEPTH*12.
C
C     SELECT PROPER DEPTH
```

```
C
      IF(DEPTH.LE..5) GO TO 1
      IF((DEPTH.LE.1.0).AND.(DEPTH.GT.0.5)) GO TO 2
      IF((DEPTH.LE.1.5).AND.(DEPTH.GT.1.0)) GO TO 3
      IF((DEPTH.LE.2.0).AND.(DEPTH.GT.1.5)) GO TO 4
      IF((DEPTH.LE.2.5).AND.(DEPTH.GT.2.0)) GO TO 5
      IF((DEPTH.LT.3.0).AND.(DEPTH.GT.2.5)) GO TO 6
      IF((DEPTH.LE.3.5).AND.(DEPTH.GT.3.0)) GO TO 7
      IF((DEPTH.LE.4.0).AND.(DEPTH.GT.3.5)) GO TO 8
C
C     FOR DEPTHS LARGER THAN LAST SHEAR STRENGTH TAKE THE ARITHMETIC
C     AVERAGE OF THE LAST THREE AND CALL IT CONSTANT
C
      IF(DEPTH.GT.4.0) GO TO 9
C
C     FORMULAS FOR SHEAR STRENGTH FOLLOW
C     LINEAR VARIATION BETWEEN MEASURED POINTS IS ASSUMED
C
    1 SSS=SLOPE1*DEPTH
      GO TO 10
    2 SSS=SLOPE2*DEPTH+BINT2
      GO TO 10
    3 SSS=SLOPE3*DEPTH+BINT3
      GO TO 10
    4 SSS=SLOPE4*DEPTH+BINT4
      GO TO 10
    5 SSS=SLOPE5*DEPTH+BINT5
      GO TO 10
    6 SSS=SLOPE6*DEPTH+BINT6
      GO TO 10
    7 SSS=SLOPE7*DEPTH+BINT7
      GO TO 10
    8 SSS=SLOPE8*DEPTH+BINT8
      GO TO 10
    9 SSS=(SS30+SS305+SS40)/3.
C
C     SPS IS THE SHEAR STRENGTH IN POUNDS PER SQUARE FOOT
   10 SPS=SSS*144.
C     CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C     ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X SPS X DX
      CT=CFOOT*CNC
      WS(I)=CT*SPS*AREA(I)*DX
      AMASS1=(AMASS(I)*V(I)**2/2.)
      VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I))/(BMASS+DMASS(I)+AMASS(I))
      IF (VELOSQ.LE.0.0)GO TO 1000
      V(I+1)=SQRT(VELOSQ)
C
C
```

```
C     SECTION TO COMPUTE THE WORK DONE BY DRAG
C     APPROXIMATE AVERAGE VELOCITY OVER A SECTION BY NEGLECTING THE DRAG
C     FIRST TIME OVER THE SECTION, AS DONE ABOVE
      VAVG=(V(I)+V(I+1))/2.
      IF(I.EQ.1) VAVG=(V0+V(I+1))/2.
      WDRAG=.5*BWD*CD*AREA(I)*DX*VAVG**2
C
      VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I)-WDRAG)/(BMASS+DMASS(I)+AMAS
     2S(I))
      IF (VELOSQ.LE.0.0)GO TO 1000
      V(I+1)=SQRT(VELOSQ)
C
C     CALCULATE E AT NEXT SECTION
      E(I+1)=BMASS*V(I+1)**2/2.
C
C     CALCULATE ENERGY DISSIPATED BY ADDED MASS EFFECTS, EAM
      EAM=.5*(AMASS(I)*V(I+1)**2-2.0*AMASS1+DMASS(I)*V(I+1)**2)
C
C     COMPUTE PENETRATION DEPTH
      XXX=I*DX
C
C     PRINT THE SECTION, DEPTH OF PENETRATION, VELOCITY AT THE END OF
C     SECTION, SHEAR STRENGTH IN SECTION, BODY ENERGY AT END OF SECTION,
C     WORKDONE BY   SEDIMENT, ADDED MASS PLUS DISPLACED MASS, BUOYANCY,
C     AND DRAG
C
      WRITE(6,2600) I,XXX,V(I+1),SPS,E(I+1),WS(I),EAM,WB(I),WDRAG
 2000 CONTINUE
 1000 CONTINUE
 2050 FORMAT(I5)
 2060 FORMAT(' ',I3)
 2100 FORMAT(F5.1,8F5.2)
 2200 FORMAT('1',9X,'SPHERE'//9X,'RADIUS = ',F7.3/9X,'WEIGHT = ',F7.1,'
    2LBS'/9X,'BULK WET DENSITY = ',F5.2,'SLUGS PER CUBIC FOOT'/9X,'DRAG
    3 COEFFICIENT = ',F5.2///)
 2300 FORMAT(' ',10X,'IMPACT VELOCITY EQUALS',F5.1///10X,'SEDIMENT SHEAR
    2 STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE'//15X,8F6.2//)
 2500 FORMAT('0',28X,'CONDITIONS AT THE END OF SECTION',19X,'WORK DONE I
    2N SECTION - FOOT POUNDS'///16X,'ITERATION',1X,'PENETRATION',4X,'VE
    3LOCITY',3X,'SHEAR',5X,'BODY ENERGY',6X,'STATIC',4X,'SEDIMENT',5X,'
    4BUOYANT',3X,'FORM DRAG'/17X,'SECTION',6X,'FEET',8X,'FT/SEC',2X,'ST
    5RENGTH PSF',4X,'FT-LBS',7X,'FORCES',4X,'INERTIA',6X,'FORCES',4X,'F
    6ORCES'//)
 2600 FORMAT(' ',16X,I3,3X,F12.2,7F12.3)
      STOP
      END
```

```
SPHERE

RADIUS =     1.192
WEIGHT =     561.0 LBS
BULK WET DENSITY =   2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =   0.30


 IMPACT VELOCITY EQUALS  0.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
       0.30  0.38  0.78  0.70  1.34  1.63  1.53  1.55


                      CONDITIONS AT THE END OF SECTION
                                                                  WORK DONE IN SECTION - FOOT POUNDS

    ITERATION PENETRATION      VELOCITY   SHEAR       BODY ENERGY       STATIC      SEDIMENT       BUOYANT     FORM DRAG
     SECTION      FEET          FT/SEC  STRENGTH PSF     FT-LBS         FORCES      INERTIA        FORCES      FORCES

        1         0.05          1.787      1.080        27.332          0.074        0.121         0.020        0.003
        2         0.10          2.487      3.240        53.726          0.653        1.352         0.100        0.051
        3         0.15          2.977      5.400        76.953          1.775        2.653         0.256        0.135
        4         0.20          3.331      7.560        95.945          3.407        3.928         0.496        0.246
        5         0.25          3.601      9.720       111.323          5.496        5.017         0.785        0.375
        6         0.30          3.801     11.880       123.391          8.020        5.801         1.151        0.510
        7         0.35          3.927     14.040       134.573         10.936        6.205         1.580        0.641
        8         0.40          3.994     16.200       139.415         14.206        6.181         2.068        0.759
        9         0.45          4.016     18.360       140.492         17.792        5.711         2.612        0.858
       10         0.50          3.979     20.520       137.949         21.658        4.796         3.209        0.929
       11         0.55          3.890     22.680       131.956         25.764        3.453         3.856        0.969
       12         0.60          3.755     24.840       122.700         30.074        1.710         4.548        0.975
       13         0.65          3.553     27.000       110.373         34.550       -0.398         5.282        0.943
       14         0.70          3.304     29.160        96.171         39.154       -2.829         6.055        0.872
       15         0.75          2.977     31.320        77.286         43.947       -5.539         6.864        0.762
       16         0.80          2.555     33.480        56.706         48.594       -8.480         7.705        0.613
       17         0.85          1.981     35.640        34.208         53.355      -11.607         8.574        0.425
       18         0.90          1.037     37.800         9.370         58.093      -14.867         9.469        0.193
```

```
SPHERE

RADIUS =    1.192
WEIGHT =    561.0 LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  0.30


 IMPACT VELOCITY EQUALS  5.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
       0.36  1.04  1.03  1.56  2.41  2.68  2.61  2.16


              CONDITIONS AT THE END OF SECTION
                                                               WORK DONE IN SECTION - FOOT POUNDS
 ITERATION PENETRATION    VELOCITY    SHEAR    BODY ENERGY      STATIC      SEDIMENT      BUOYANT     FORM DRAG
  SECTION      FEET        FT/SEC  STRENGTH PSF   FT-LBS        FORCES      INERTIA       FORCES      FORCES

    1          0.05        5.293       1.296     244.746        0.089        1.060        0.020        0.100
    2          0.10        5.534       3.888     266.986        0.784        4.600        0.100        0.325
    3          0.15        5.716       6.480     285.087        2.130        6.939        0.256        0.573
    4          0.20        5.805       9.072     293.390        4.082        8.849        0.486        0.830
    5          0.25        5.946      11.664     303.283        6.595       10.192        0.785        1.084
    6          0.30        5.974      14.256     312.250        9.624       10.983        1.151        1.326
    7          0.35        6.003      16.848     313.658       13.123       11.195        1.580        1.544
    8          0.40        5.905      19.440     310.240       17.047       10.823        2.068        1.730
    9          0.45        5.891      22.032     302.573       21.351        9.876        2.612        1.877
   10          0.50        5.775      24.624     291.060       25.989        8.332        3.209        1.981
   11          0.55        5.628      27.216     275.923       30.917        6.278        3.856        2.036
   12          0.60        5.429      29.808     257.385       36.089        3.909        4.548        2.041
   13          0.65        5.194      32.400     235.673       41.460        1.025        5.282        1.995
   14          0.70        4.920      34.992     211.064       46.984       -2.217        6.055        1.896
   15          0.75        4.569      37.584     183.590       52.617       -5.763        6.864        1.745
   16          0.80        4.193      40.176     153.632       58.313       -9.555        7.705        1.545
   17          0.85        3.730      42.768     121.320       64.026      -13.536        8.574        1.298
   18          0.90        3.156      45.360      86.636       69.712      -17.652        9.469        1.005
   19          0.95        2.403      47.952      50.351       75.325      -21.846       10.385        0.670
   20          1.00        1.175      50.544      12.036       80.821      -26.059       11.320        0.283
```

```
SPHERE

RADIUS =     1.192
WEIGHT =     561.0 LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  0.30


 IMPACT VELOCITY EQUALS 10.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

      0.49  0.77  0.85  2.07  2.43  1.19  1.19  1.77


                      CONDITIONS AT THE END OF SECTION                     WORK DONE IN SECTION - FOOT POUNDS

      ITERATION PENETRATION     VELOCITY   SHEAR     BODY ENERGY       STATIC      SEDIMENT      BUOYANT    FORM DRAG
       SECTION      FEET         FT/SEC  STRENGTH PSF   FT-LBS         FORCES      INERTIA       FORCES     FORCES

          1          0.05        10.135      1.764      895.509         0.121        3.878        0.020       0.383
          2          0.10        10.199      5.292      906.826         1.067       14.349        0.100       1.146
          3          0.15        10.216      8.820      909.566         2.899       20.019        0.256       1.885
          4          0.20        10.192     12.348      905.645         5.556       23.659        0.486       2.530
          5          0.25        10.131     15.876      894.373         8.977       25.845        0.785       3.216
          6          0.30        10.026     19.404      878.120        13.099       26.762        1.151       3.782
          7          0.35         9.903     22.932      855.917        17.962       26.553        1.580       4.268
          8          0.40         9.739     26.460      828.697        23.203       25.330        2.068       4.669
          9          0.45         9.539     29.988      796.897        29.061       23.195        2.612       4.980
         10          0.50         9.312     33.516      760.915        35.374       20.250        3.209       5.198
         11          0.55         9.094     37.044      721.115        42.082       16.590        3.856       5.323
         12          0.60         8.817     40.572      677.829        49.121       12.311        4.548       5.355
         13          0.65         8.510     44.100      631.362        56.432        7.506        5.282       5.297
         14          0.70         8.170     47.628      581.991        63.951        2.263        6.055       5.151
         15          0.75         7.797     51.156      529.670        71.617       -3.332        6.864       4.921
         16          0.80         7.385     54.684      475.578        79.370       -9.197        7.705       4.613
         17          0.85         6.931     58.212      418.873        87.147      -15.253        8.574       4.231
         18          0.90         6.428     61.740      360.214        94.886      -21.424        9.469       3.782
         19          0.95         5.863     65.268      299.717       102.526      -27.638       10.385       3.273
         20          1.00         5.220     68.796      237.558       110.006      -33.826       11.320       2.709
         21          1.05         4.475     71.568      174.597       116.038      -39.389       12.270       2.102
         22          1.10         3.578     73.584      111.614       120.523      -44.196       13.231       1.465
         23          1.15         2.364     75.600       48.726       124.634      -48.700       14.200       0.803
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```
IMPACT VELOCITY EQUALS 15.0                                                 SPHERE

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE           RADIUS =     1.192
                                                                           WEIGHT =    561.0 LBS
                                                                           BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
      0.30  0.37  0.45  2.44  2.78  2.78  2.86  3.14                       DRAG COEFFICIENT =  0.30


               CONDITIONS AT THE END OF SECTION                            WORK DONE IN SECTION - FOOT POUNDS

 ITERATION PENETRATION     VELOCITY   SHEAR       BODY ENERGY      STATIC     SEDIMENT      BUOYANT    FORM DRAG
  SECTION     FEET          FT/SEC  STRENGTH PSF    FT-LBS         FORCES     INERTIA       FORCES     FORCES

     1           0.05        15.071       1.080     1980.215        0.074       8.576        0.020        0.854
     2           0.10        15.043       3.240     1974.368        0.653      30.629        0.100        2.516
     3           0.15        14.972       5.400     1954.411        1.775      41.399        0.256        4.076
     4           0.20        14.856       7.560     1924.218        3.402      48.844        0.486        5.511
     5           0.25        14.709       9.720     1886.209        5.496      52.972        0.735        6.805
     6           0.30        14.535      11.880     1842.166        8.020      54.970        1.151        7.952
     7           0.35        14.342      14.040     1793.470       10.936      55.280        1.580        8.949
     8           0.40        14.132      16.200     1741.219       14.206      54.230        2.068        9.797
     9           0.45        13.907      18.360     1686.282       17.792      52.000        2.612       10.500
    10           0.50        13.670      20.520     1629.354       21.653      49.048        3.209       11.064
    11           0.55        13.423      22.680     1570.980       25.764      45.209        3.856       11.495
    12           0.60        13.167      24.840     1511.595       30.074      41.012        4.548       11.802
    13           0.65        12.903      27.000     1451.536       34.550      36.234        5.282       11.991
    14           0.70        12.631      29.160     1391.074       39.154      31.233        6.055       12.071
    15           0.75        12.353      31.320     1330.416       43.847      25.947        6.864       12.050
    16           0.80        12.069      33.480     1269.723       48.594      20.508        7.705       11.936
    17           0.85        11.776      35.640     1209.123       53.355      14.934        8.574       11.737
    18           0.90        11.473      37.800     1148.715       58.093       9.435        9.469       11.460
    19           0.95        11.174      39.960     1088.573       62.771       3.916       10.395       11.115
    20           1.00        10.863      42.120     1028.775       67.351      -1.525       11.320       10.707
    21           1.05        10.548      43.632      970.116       70.452      -6.263       12.270       10.249
    22           1.10        10.235      43.956      913.365       71.995     -10.190       13.231        9.755
    23           1.15         9.923      44.460      858.489       73.297     -13.809       14.200        9.237
    24           1.20         9.607      44.964      804.673       74.348     -17.814       16.636        8.695
    25           1.25         9.365      45.801      764.627       75.731     -33.453       17.611        8.206
    26           1.30         9.109      46.809      723.373       77.398     -34.462       18.587        7.780
    27           1.35         8.837      47.817      680.919       79.064     -35.465       19.562        7.343
    28           1.40         8.549      48.825      637.270       80.731     -36.462       20.537        6.892
    29           1.45         8.243      49.833      592.434       82.398     -37.454       21.512        6.429
    30           1.50         7.917      50.841      546.418       84.065     -38.440       22.487        5.954
    31           1.55         7.567      51.849      499.228       85.731     -39.420       23.462        5.466
    32           1.60         7.191      52.857      450.871       87.398     -40.395       24.438        4.966
    33           1.65         6.784      53.948      401.279       89.203     -41.427       25.413        4.453
    34           1.70         6.340      55.100      350.404       91.108     -42.499       26.388        3.927
    35           1.75         5.849      56.252      298.255       93.012     -43.564       27.363        3.387
    36           1.80         5.299      57.404      244.837       94.917     -44.623       28.338        2.834
    37           1.85         4.670      58.556      190.160       96.822     -45.675       29.313        2.266
    38           1.90         3.924      59.708      134.231       98.727     -46.721       30.288        1.694
    39           1.95         2.973      60.860       77.059      100.632     -47.759       31.264        1.085
    40           2.00         1.463      62.012       18.665      102.536     -48.780       32.239        0.449
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SPHERE

RADIUS =    1.192
WEIGHT =    561.0 LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  0.30


 IMPACT VELOCITY EQUALS  5.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
       0.40  0.52  1.08  1.51  1.74  1.95  2.11  2.44


             CONDITIONS AT THE END OF SECTION
                                                                    WORK DONE IN SECTION - FOOT POUNDS

     ITERATION PENETRATION     VELOCITY   SHEAR        BODY ENERGY
      SECTION     FEET          FT/SEC  STRENGTH PSF      FT-LBS        STATIC     SEDIMENT      BUOYANT     FORM DRAG
                                                                        FORCES     INERTIA       FORCES      FORCES

         1         0.05         5.298       1.440      244.736        0.099        1.060        0.020        0.100
         2         0.10         5.533       4.320      266.892        0.871        4.597        0.100        0.325
         3         0.15         5.715       7.200      284.773        2.366        6.973        0.256        0.572
         4         0.20         5.848      10.080      298.171        4.536        8.802        0.486        0.828
         5         0.25         5.933      12.960      306.937        7.328       10.090        0.785        1.081
         6         0.30         5.973      15.840      311.030       10.693       10.795        1.151        1.318
         7         0.35         5.968      18.720      310.501       14.581       10.887        1.580        1.530
         8         0.40         5.919      21.600      305.476       18.941       10.358        2.068        1.707
         9         0.45         5.828      24.480      296.128       23.723        9.218        2.612        1.843
        10         0.50         5.694      27.360      282.664       28.877        7.495        3.209        1.931
        11         0.55         5.516      30.240      265.310       34.352        5.227        3.856        1.968
        12         0.60         5.293      33.120      244.300       40.099        2.463        4.548        1.950
        13         0.65         5.022      36.000      219.866       46.067       -0.743        5.282        1.877
        14         0.70         4.696      38.880      192.239       52.205       -4.332        6.055        1.748
        15         0.75         4.306      41.760      161.641       58.463       -8.244        6.864        1.564
        16         0.80         3.836      44.640      128.284       64.792      -12.417        7.705        1.327
        17         0.85         3.255      47.520       92.373       71.140      -16.791        8.574        1.038
        18         0.90         2.491      50.400       54.100       77.458      -21.303        9.469        0.700
        19         0.95         1.252      53.280       13.656       83.695      -25.890       10.385        0.304
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SPHERE

RADIUS =    1.192
WEIGHT =    561.0 LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  0.30

 IMPACT VELOCITY EQUALS 10.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
       0.69  0.66  0.77  1.39  1.56  2.05  2.44  3.01

              CONDITIONS AT THE END OF SECTION                    WORK DONE IN SECTION - FOOT POUNDS

   ITERATION PENETRATION    VELOCITY   SHEAR    BODY ENERGY     STATIC      SEDIMENT      BUOYANT     FORM DRAG
    SECTION     FEET        FT/SEC  STRENGTH PSF   FT-LBS       FORCES      INERTIA       FORCES      FORCES

       1        0.05        10.134     2.434     895.460       0.171        3.878        0.020       0.383
       2        0.10        10.196     7.452     906.428       1.502       14.333        0.100       1.146
       3        0.15        10.207    12.420     908.317       4.082       19.939        0.256       1.883
       4        0.20        10.172    17.388     902.069       7.824       23.435        0.486       2.572
       5        0.25        10.093    22.356     888.141      12.641       25.325        0.785       3.197
       6        0.30         9.972    27.324     867.029      18.445       25.872        1.151       3.744
       7        0.35         9.810    32.292     839.134      25.152       25.013        1.580       4.199
       8        0.40         9.603    37.260     804.279      32.673       23.008        2.068       4.556
       9        0.45         9.365    42.228     764.678      40.922       19.907        2.612       4.808
      10        0.50         9.081    47.196     718.941      49.813       15.215        3.209       4.950
      11        0.55         8.754    52.164     668.059      59.258       10.837        3.856       4.981
      12        0.60         8.381    57.132     612.405      69.171        5.084        4.548       4.901
      13        0.65         7.959    62.100     552.332      79.465       -1.335        5.282       4.711
      14        0.70         7.483    67.068     488.169      90.053       -8.311        6.055       4.415
      15        0.75         6.943    72.036     420.227     100.849      -15.739        6.864       4.017
      16        0.80         6.325    77.004     348.794     111.766      -23.511        7.705       3.523
      17        0.85         5.607    81.972     274.140     122.717      -31.528        8.574       2.940
      18        0.90         4.748    86.940     196.521     133.615      -39.688        9.469       2.273
      19        0.95         3.650    91.908     116.179     144.374      -47.895       10.385       1.528
      20        1.00         1.956    96.876      33.355     154.906      -56.047       11.320       0.694
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IMPACT VELOCITY EQUALS 15.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.28 0.36 0.91 1.39 1.74 1.57 2.05 2.70

	CONDITIONS AT THE END OF SECTION				WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	15.071	1.008	1980.220	0.069	8.576	0.020	0.854
2	0.10	15.049	3.024	1974.415	0.610	30.630	0.100	2.516
3	0.15	14.973	5.040	1954.567	1.657	41.907	0.256	4.077
4	0.20	14.867	7.056	1924.576	3.175	48.867	0.486	5.512
5	0.25	14.721	9.072	1886.881	5.130	53.023	0.785	6.807
6	0.30	14.540	11.088	1843.275	7.485	55.065	1.151	7.956
7	0.35	14.349	13.104	1795.148	10.207	55.434	1.590	8.956
8	0.40	14.142	15.120	1743.692	13.259	54.462	2.068	9.809
9	0.45	13.921	17.136	1689.506	16.606	52.409	2.612	10.517
10	0.50	13.690	19.152	1633.512	20.214	49.491	3.209	11.039
11	0.55	13.446	21.168	1576.296	24.047	45.834	3.856	11.529
12	0.60	13.196	23.184	1518.137	28.069	41.734	4.548	11.847
13	0.65	12.938	25.200	1459.440	32.247	37.168	5.282	12.049
14	0.70	12.674	27.216	1400.457	36.543	32.290	6.055	12.144
15	0.75	12.404	29.232	1341.390	40.924	27.188	6.864	12.140
16	0.80	12.123	31.248	1282.397	45.354	21.940	7.705	12.044
17	0.85	11.847	33.264	1223.598	49.798	16.612	8.574	11.865
18	0.90	11.560	35.280	1165.076	54.220	11.262	9.469	11.610
19	0.95	11.256	37.296	1106.934	58.586	5.943	10.385	11.287
20	1.00	10.970	39.312	1049.200	62.861	0.699	11.320	10.904
21	1.05	10.670	40.608	992.590	65.840	-3.920	12.270	10.469
22	1.10	10.371	41.184	937.767	67.455	-7.811	13.231	9.998
23	1.15	10.073	41.760	884.704	68.846	-11.434	14.200	9.501
24	1.20	9.772	42.336	832.589	70.002	-15.452	16.636	8.979
25	1.25	9.547	43.292	794.637	71.583	-31.703	17.611	8.509
26	1.30	9.303	44.444	755.337	73.488	-32.830	18.587	8.105
27	1.35	9.054	45.596	714.695	75.393	-33.950	19.562	7.687
28	1.40	8.794	46.748	672.720	77.298	-35.064	20.537	7.254
29	1.45	8.497	47.900	629.418	79.202	-36.172	21.512	6.908
30	1.50	8.190	49.052	584.799	81.107	-37.274	22.487	6.348
31	1.55	7.862	50.204	538.868	83.012	-38.369	23.462	5.874
32	1.60	7.509	51.356	491.634	84.917	-39.459	24.438	5.387
33	1.65	7.101	56.433	439.577	93.312	-43.486	25.413	4.866
34	1.70	6.603	64.353	380.173	106.408	-49.624	26.388	4.282
35	1.75	5.996	72.273	313.463	119.503	-55.727	27.363	3.620
36	1.80	5.241	80.193	239.490	132.599	-61.794	28.338	2.879
37	1.85	4.261	88.113	158.207	145.695	-67.825	29.313	2.059
38	1.90	2.832	96.033	69.935	158.790	-73.814	30.288	1.148

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SPHERE

RADIUS =     1.192
WEIGHT =     561.0 LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  0.30


 IMPACT VELOCITY EQUALS 20.0


SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

       0.52  1.04  1.74  2.29  2.30  2.69  2.70  2.79


                  CONDITIONS AT THE END OF SECTION                    WORK DONE IN SECTION - FOOT POUNDS

ITERATION PENETRATION    VELOCITY   SHEAR     BODY ENERGY      STATIC      SEDIMENT        BUOYANT     FORM DRAG
 SECTION      FEET        FT/SEC  STRENGTH PSF   FT-LBS        FORCES      INERTIA         FORCES      FORCES

     1          0.05       20.032       1.872    3498.678        0.129      15.153          0.020        1.513
     2          0.10       19.943       5.616    3457.680        1.132      53.392          0.100        4.431
     3          0.15       19.755 [illegible]    3412.918        3.076      72.336          0.256        7.139
     4          0.20       19.577      13.104    3341.455        5.896      83.521          0.486        9.597
     5          0.25       19.320 [illegible]  [illegible]       9.526      89.709          0.785       11.786
     6          0.30  [illegible] [illegible]  [illegible]      13.901      92.179          1.151       13.693
     7          0.35       18.750 [illegible]  [illegible]      18.355      91.755          1.580       15.334
     8          0.40  [illegible] [illegible]    2960.852       24.623      89.046          2.048       16.702
     9          0.45  [illegible] [illegible]  [illegible]      30.940      84.577          2.612       17.810
    10          0.50  [illegible] [illegible]    2742.143       37.940      78.585          3.209       18.674
    11          0.55  [illegible] [illegible]    2651.832       44.656      71.532          3.856       19.306
    12          0.60       17.001 [illegible]  [illegible]      52.129      63.676          4.548       19.723
    13          0.65       16.618 [illegible]  [illegible]      59.887      55.084          5.282       19.939
    14          0.70       16.227 [illegible]    2295.749       67.966      46.039          6.035       19.972
    15          0.75       15.828 [illegible]    2184.309       76.002      36.739          6.864       19.835
    16          0.80       15.422 [illegible]    2073.572       84.229      27.308          7.705       19.545
    17          0.85  [illegible]      61.776  [illegible]      92.382      17.762          8.574       19.115
    18          0.90  [illegible] [illegible]  [illegible]     100.495       8.247          9.469       18.559
    19          0.95       14.155 [illegible]    1746.897      108.803      -1.150         10.385       17.892
    20          1.00       13.716 [illegible]    1640.103      116.741     -10.354         11.320       17.127
    21          1.05       13.266      76.752  [illegible]     124.443     -19.296         12.270       16.276
    22          1.10       12.807      80.476    1429.983      131.844     -27.908         13.231       15.353
    23          1.15       12.335      84.240    1326.726      139.878     -36.136         14.200       14.369
    24          1.20       11.849      87.984    1223.921      147.481     -44.597         15.636       13.334
    25          1.25       11.425      94.199    1125.014      155.757     -71.763         17.611       12.349
    26          1.30       10.950 [illegible]    1045.341      168.138     -77.416         18.597       11.414
    27          1.35       10.416     107.175     945.938      180.520     -83.037         19.562       10.408
    28          1.40        9.915 [illegible]     834.844      192.901     -88.627         20.537        9.331
    29          1.45        9.132 [illegible]     727.019      205.232     -94.184         21.512        8.185
    30          1.50        8.349 [illegible]     607.737      217.664     -99.709         22.487        6.968
    31          1.55        7.434     139.127     481.801      230.045    -105.202         23.462        5.680
    32          1.60        6.230     146.615     345.329      242.426    -110.662         24.438        4.320
    33          1.65        4.896 [illegible]     200.013      257.293    -117.215         25.413        2.874
    34          1.70        2.622 [illegible]  [illegible]     273.960    -124.523         26.388        1.290
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SPHERE

RADIUS =     1.192
WEIGHT =     561.0 LBS
BULK WET DENSITY =   2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =   0.30


IMPACT VELOCITY EQUALS 20.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
      0.71  0.71  1.45  I.74  2.09  2.21  2.38  2.30


                CONDITIONS AT THE END OF SECTION                               WORK DONE IN SECTION - FOOT POUNDS

ITERATION PENETRATION     VELOCITY   SHEAR       BODY ENERGY        STATIC      SEDIMENT      BUOYANT     FORM DRAG
 SECTION      FEET         FT/SEC  STRENGTH PSF    FT-LBS            FORCES      INERTIA       FORCES      FORCES

     1         0.05        20.032      2.556      3498.631           0.175       15.152         0.020        1.513
     2         0.10        19.942      7.668      3467.232           1.546       53.367         0.100        4.431
     3         0.15        19.781     12.780      3411.424           4.200       72.259         0.256        7.137
     4         0.20        19.567     17.892      3338.043           8.051       83.299         0.486        9.590
     5         0.25        19.311     23.004      3251.307          13.007       89.224         0.785       11.768
     6         0.30        19.021     28.116      3154.273          18.980       91.286         1.151       13.662
     7         0.35        18.701     33.228      3049.293          25.881       90.292         1.580       15.269
     8         0.40        18.356     38.340      2938.217          33.620       86.039         2.062       16.595
     9         0.45        17.993     43.452      2822.488          42.109       81.402         2.612       17.647
    10         0.50        17.608     48.564      2703.256          51.257       74.371         3.209       18.438
    11         0.55        17.207     53.676      2581.424          60.976       66.068         3.856       18.981
    12         0.60        16.790     58.788      2457.689          71.176       56.761         4.548       19.291
    13         0.65        16.357     63.900      2332.611          81.768       46.697         5.282       19.383
    14         0.70        15.909     69.012      2206.623          92.663       36.046         6.055       19.274
    15         0.75        15.446     74.124      2080.057         103.772       25.001         6.864       18.978
    16         0.80        14.967     79.236      1953.178         115.005       13.709         7.705       18.512
    17         0.85        14.473     84.348      1826.188         126.274        2.209         8.574       17.892
    18         0.90        13.961     89.460      1699.256         137.488       -9.107         9.469       17.133
    19         0.95        13.430     94.572      1572.511         148.558      -20.401        10.385       16.251
    20         1.00        12.879     99.684      1446.068         159.396      -31.486        11.320       15.261
    21         1.05        12.315    102.240      1322.361         165.769      -40.473        12.270       14.191
    22         1.10        11.750    102.240      1203.691         167.458      -47.048        13.231       13.030
    23         1.15        11.181    102.240      1089.920         168.553      -52.885        14.200       11.953
    24         1.20        10.603    102.240       980.122         169.053      -58.661        16.636       10.818
    25         1.25        10.094    102.240       888.379         169.053      -76.628        17.611        9.766
    26         1.30         9.559    102.240       796.628         169.053      -76.645        18.587        8.806
    27         1.35         8.991    102.240       704.869         169.053      -76.652        19.562        7.846
    28         1.40         8.386    102.240       613.102         169.053      -76.659        20.537        6.885
    29         1.45         7.733    102.240       521.327         169.053      -76.665        21.512        5.924
    30         1.50         7.019    102.240       429.545         169.053      -76.671        22.487        4.962
    31         1.55         6.224    102.240       337.757         169.053      -76.677        23.462        3.999
    32         1.60         5.311    102.240       245.963         169.053      -76.681        24.438        3.034
    33         1.65         4.129    108.420       148.615         179.272      -81.320        25.413        2.032
    34         1.70         2.188    119.076        41.748         196.891      -89.273        26.388        0.911
```

APPENDIX D: COMPUTATION OF A CYLINDER PENETRATING HORIZONTALLY

```
C DYNAMIC PENETRATION OF AN OBJECT INTO THE OCEAN BOTTOM
C PROGRAM TO CALCULATE SECTION PROPERTIES OF A CYLINDER ON ITS SIDE
C
C UNITS FEET/POUNDS/SLUGS/SECONDS/
C
C DX      INCREMENT SIZE
C
C BWD     BULK WET DENSITY OF SEDIMENT
C
C BMASS   OBJECT MASS
C
C AMASS() ADDED MASS PLUS MASS OF DISPLACED SEDIMENT AT SECTION ( )
C
C DMASS( )CHANGE IN AMASS OVER SECTION INDICATED BY SUBSCRIPT
C
C AREA( ) PROJECTED AREA FOR SECTION ( )
C
C CNC     BEARING CAPACITY COEFFICIENT
C
C VOL( )  VOLUME OF SECTION ( )
C
C CFOOT   BEARING CAPACITY CONSTANT DEPENDS ON SHAPE OF AREA
C
C XXX     DEPTH OF PENETRATION
C
C SVOL( ) SUM OF VOLUMES TO SECTION INDICATED
C
C V( )    VELOCITY OF OBJECT AT SECTION ( )
C
C WS( )   WORK DONE BY SEDIMENT IN SECTION ( )
C
C WT      WEIGHT OF OBJECT
C
C G       ACCELERATION OF GRAVITY
C
C SPS     SHEAR STRENGTH OF SEDIMENT
C
C RAD     RADIUS
C
C DIM     LENGTH OF CYLINDER
C
C WDRAG   WORK DONE BY DRAG FORCES
C
C WB( )   WORK DONE BY BUOYANCY WHEN SUBMERGING TO SECTION ( )
C
```

```
C WBSUB( )WORK DONE BY SUBMERGED SECTION ( )
C
C US( )    WORK TO SUBMERGE SECTION ( )
C
C SUMSUB()WORK DONE BY SUBMERGED SECTIONS TO SECTION( )
C
C E( )    KINETIC ENERGY OF BODY AT SECTION( )
C
C
C
      DIMENSION AREA(100),VOL(100),AMASS(100),DMASS(100),SVOL(100),WS(10
     20),WB(100),WBSUB(100),US(100),SUMSUB(100),E(100),V(100)
      DATA PI/3.141593/,G/32.1725/,AREA/100*0.0/,VOL/100*0.0/,AMASS/100*
     20.0/,DMASS/100*0.0/,SVOL/100*0.0/,WS/100*0.0/,WB/100*0.0/,WBSUB/10
     30*0.0/,US/100*0.0/,SUMSUB/100*0.0/,E/100*0.0/,V/100*0.0/
C
C
C
C     INPUT DATA ON OBJECT
C     OBJECT HORIZONTAL CYLINDER
      RAD=.94791
      WT=540.75
      DIM=33.834/12.
      RWD=87.402/G
      CFOOT=1.3
      CNC=5.7
C     COHESION OR SHEAR STRENGTH IN PSI EQUALS .3 FOR PROGRAM CHECKOUT
      COH=43.2
C
C     FOR A CYLINDER USE A COEFFICIENT OF DRAG EQUAL TO 0.68
      CD=0.68
C
C
C     SET INCREMENT
      DX=.05
C
C
C
C     CALCULATE THE SECTION PROPERTIES,AVERAGE PROJECTED AREA,VOLUME
C     FIND AREA AT MIDPOINT OF EACH SECTION
C     Y=DISTANCE ABOVE BOTTOM OF SPHERE
      Y=DX/2.
      YMAX=2*RAD
      Z=RAD/DX
      N=Z+1.
C     THE ONE ACCOUNTS FOR INTEGER TRUNCATION IN THIS PROBLEM
      DIM2=2.*(RAD**2-(RAD-Y)**2)
      AREA(1)=DIM*DIM2
      DO 100 I=2,N
      AREA(I)=DIM*2.*SQRT(RAD**2-(RAD-(I-1)*DX-Y)**2)
```

```
C     PRINT,AREA(I)
  100 CONTINUE
C
C     FOR THIS ANALYSIS AFTER THE AREA HAS BECOME A MAXIMUM IT WILL BE
C     CONSTANT FOR THE REMAINING PENETRATION THEREFORE SET SUCCEEDING
C     AREAS AS FOLLOWS
      DO 200 I=N,100
      AREA(I)=AREA(N)
C     PRINT,AREA(I)
  200 CONTINUE
C
C
C     COMPUTE THE VOLUME OF EACH SECTION
C     VOLUME EQUALS AVERAGE AREA TIMES SECTION HEIGHT
C
      DO 300 I=1,100
      VOL(I)=AREA(I)*DX
  300 CONTINUE
C
C     CHECK VOLUME CALCULATIONS
      HAFVOL=PI*RAD**2*DIM/2.
      CVOL=VOL(1)
      DO 350 I=2,N
      CVOL=CVOL+VOL(I)
  350 CONTINUE
C
      ERROR=CVOL-HAFVOL
C     PRINT,CVOL,HAFVOL,ERROR
C
C
C
C     CALCULATE ADDED MASS, DISPLACED MASS AND CHANGE IN ADDED MASS PLUS
C     DISPLACED MASS FROM SECTION TO SECTION.
C     APPROXIMATE BY USING ONE HALF OF A PROLATE ELLIPSOID.
C     AMASS BECOMES CONSTANT WHEN THE MAXIMUM AREA HAS BEEN REACHED.
C
      SUMVOL=0.0
      K=N+1
      DO 400 I=2,K
C     CHANGE THE PROJECTED RECTANGULAR AREA INTO A ELLIPSE OF THE
C     EQUIVALENT AREA KEEPING THE RATIO OF MAXIMUM AND MINIMUM
C     DIMENSIONS THE SAME FOR THE RECTANGLE AND ELLIPSE
      AA=DIM
      BB=2.*SQRT(RAD**2-(RAD-(I-1)*DX-Y)**2)
C     THE ELLIPSE DIMENSIONS ARE
      A=SQRT(DIM**2/PI)
      P=AA/BB
      B=A/P
```

```
      REA=PI*A*B
C     PRINT,A,B,REA
C     NOW FORM THE APPROXIMATE PROLATE ELLIPSOID USING DIMENSIONS OF
C     EQUIVALENT ELLIPSE AND PENETRATION DEPTH
C     SEE PAGE 421 OF SAUNDERS FOR FORMULAS BELOW
C     EK IS A VARIABLE OF HYPERBOLIC FORM FOR THE ADDED MASS EQUATION
C     APPROXIMATE EK BY A SERIES OF STRAIGHT LINES
      IF(R.LE.1.0) GO TO 400
      IF((R.LE.1.50).AND.(R.GT.1.00)) GO TO 12
      IF((R.LE.2.00).AND.(R.GT.1.50)) GO TO 13
      IF((R.LE.2.51).AND.(R.GT.2.00)) GO TO 14
      IF((R.LE.2.99).AND.(R.GT.2.51)) GO TO 15
      IF((R.LE.3.99).AND.(R.GT.2.99)) GO TO 16
      IF((R.LE.4.99).AND.(R.GT.3.99)) GO TO 17
      IF((R.LE.6.01).AND.(R.GT.4.99)) GO TO 18
      IF((R.LE.6.97).AND.(R.GT.6.01)) GO TO 19
      IF(R.GT.6.97) GO TO 20
   12 EK=.2420*R+.2580
      GO TO 21
   13 EK=.1620*R+.3780
      GO TO 21
   14 EK=.1196*R+.4628
      GO TO 21
   15 EK=.0833*R+.5629
      GO TO 21
   16 EK=.0570*R+.6326
      GO TO 21
   17 EK=.0350*R+.7204
      GO TO 21
   18 EK=.0226*R+.7825
      GO TO 21
   19 EK=.0156*R+.8241
      GO TO 21
   20 EK=.0090*R+.8703
      GO TO 21
C
C     NOW ADDED MASS,DESIGNATE SOME NEW VARIABLES
C     AND DISPLACED VOL AT THE SAME TIME
   21 AMASS(I-1)=EK*(2./3.)*BWD*PI*A*B**2
C
C     SUM THE VOLUMES BEFORE ADDING
C
      SUMVOL=SUMVOL+VOL(I-1)
C     SUMVOL AT END OF DO LOOP SHOULD EQUAL HAFVOL
      AMASS(I-1)=AMASS(I-1)+BWD*SUMVOL
C     PRINT,AA,BB,A,B,R,EK,AMASS(I-1)
  400 CONTINUE
C
```

```
C
C     CHECK ADDED MASS BY COMPARING LAST INCREMENT TO ONE HALF ELLIPSOID
      HAMAS=BWD*(EK*(2./3.)*PI*A*B**2+PI*RAD**2*DIM/2.)
      ERROR=HAMAS-AMASS(N)
      PRINT,HAMAS,AMASS(N),ERROR
C
C
C     AMASS REMAINS THE SAME AFTER MAX AREA
C
      DO 450 I=N,100
      AMASS(I)=AMASS(N)
  450 CONTINUE
C
C
C
C     COMPUTE CHANGE IN AMASS FROM SECTION TO SECTION
      DMASS(1)=0.0
      DO 500 I=2,N
      DMASS(I)=AMASS(I)-AMASS(I-1)
  500 CONTINUE
C
C     SUM DMASS, IT SHOULD BE CLOSE TO AMASS(N)
C
      CDMASS=DMASS(1)
      DO 550 I=2,N
      CDMASS=CDMASS+DMASS(I)
  550 CONTINUE
      PRINT,CDMASS,AMASS(N)
C
C
C
C
C     CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C     PER SECTION IF THE SHEAR STRENGTH IS CONSTANT FOR PROGRAM CHECK
C     ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X COHESIONX DX
      CT=CFOOT*CNC
      DO 600 I=1,100
      WS(I)=CT*COH*AREA(I)*DX
  600 CONTINUE
C
C
C
C
C     CALCULATE WORK DONE BY BUOYANCY
C
      GAMMA=BWD*G
      WB(1)=(GAMMA*AREA(1)*DX**2)/2.
      SUMSUB(1)=2.0*WB(1)
      DO 700 I=2,N
C
C     WORK TO SUBMERGE SECTION
```

```
      US(I)=(GAMMA*AREA(I)*DX**2)/2.
C
C     WORK TO CONTINUE SECTION AFTER SUBMERGING
      WBSUB(I)=2.0*US(I)
C
C     TOTAL WORK OF THE SUBMERGED SECTIONS
      SUMSUB(I)=SUMSUB(I-1)+WBSUB(I)
C
C     TOTAL WORK DONE SUBMERGING SECTION PLUS THOSE ALREADY SUBMERGED
      WB(I)=US(I)+SUMSUB(I-1)
C     PRINT,WB(I)
  700 CONTINUE
C
C     AFTER ALL SECTIONS ARE SUBMERGED WORK BECOMES CONSTANT EQUAL TO
C     SUMSUB(N) PLUS WBSUB(N) FOR EACH FURTHUR INCREMENT
C     THIS ASSUMES A CAVITY IS FORMED AFTER THE OBJECT PENETRATES PAST
C     ITS MAXIMUM DIMENSION.
C
      DO 760 I=N,100
      WB(I)=SUMSUB(N)+(I-(N-1))*WBSUB(N)
C     PRINT,WB(I)
  760 CONTINUE
C
C     CHECK WORK TO SUBMERGE
C
      CWB=WB(1)
      DO 800 I=2,N
      CWB=CWB+WB(I)
  800 CONTINUE
C     PRINT,CWB
C
C
C
C
C     PROGRAM TO COMPUTE PENETRATION DEPTH FOLLOWS
C
C     BE ABLE TO DO NNN DIFFERENT VELOCITIES AND SHEAR STRENGTHS
      READ(5,2050) NNN
      WRITE(6,2060)NNN
C
      DO 1000 J=1,NNN
      WRITE(6,2200) RAD,DIM,WT,BWD,CD
C
C     READ IN THE VELOCITIES AND SHEAR STRENGTHS
      READ(5,2100) VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40
      WRITE(6,2300)VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40
      WRITE(6,2500)
C
```

```
C     CALCULATE ORIGINAL ENERGY OF BODY AT INTERFACE
      BMASS=WT/G
      E(1)=BMASS*VO**2/2.
C
C     CALCULATE POTENTIAL ENERGY FOR EACH INCREMENT
      EP=WT*DX
C
C     COMPUTE SLOPE OF SHEAR STRENGTH VARIATIONS
C
      SLOPE1=SS05/.5
      BINT1=0.0
C
      SLOPE2=(SS10-SS05)/.5
      BINT2=-SLOPE2*.5+SS05
C
      SLOPE3=(SS105-SS10)/.5
      BINT3=-SLOPE3*1.+SS10
C
      SLOPE4=(SS20-SS105)/.5
      BINT4=-SLOPE4*1.5+SS105
C
      SLOPE5=(SS205-SS20)/.5
      BINT5=-SLOPE5*2.0+SS20
C
      SLOPE6=(SS30-SS205)/.5
      BINT6=-SLOPE6*2.5+SS205
C
      SLOPE7=(SS305-SS30)/.5
      BINT7=-SLOPE7*3.+SS30
C
      SLOPE8=(SS40-SS305)/.5
      BINT8=-SLOPE8*3.5+SS305
C
C     VELOCITY OF SEDIMENT AT INTERFACE IS ALWAYS 0 AT INSTANT OF IMPACT
      V(1)=0.0
      DO 2000 I=1,100
C
C     SECTION TO COMPUTE SHEAR STRENGTH
C     NOTE THAT THE SHEAR STRENGTH IS COMPUTED IN INCHES THEN CONVERTED
C     TO POUNDS PER SQUARE FOOT FOR THE CALCULATION
C
C     FOR THE CYLINDER TAKE THE DEPTH FOR SHEAR STRENGTH TO BE THE
C     PENETRATION DEPTH MINUS ONE HALF THE PENETRATION DEPTH
      DEPTH=I*DX-Y-(I*DX-Y)/2.
C     WHEN THE MAX RAD IS REACHED THE DEPTH EQUALS PENETRATION DEPTH
C     MINUS ONE HALF THE RADIUS
      IF((I*DX-Y).GT.RAD) DEPTH=I*DX-Y-RAD/2.
C
```

```
C     CONVERT THE DEPTH TO INCHES FOR EASY COMPARISON WITH  DATA
      DEPTHI=DEPTH*12.
C
C     SELECT PROPER DEPTH
      IF(DEPTH.LE..5) GO TO 1
      IF((DEPTH.LE.1.0).AND.(DEPTH.GT.0.5)) GO TO 2
      IF((DEPTH.LE.1.5).AND.(DEPTH.GT.1.0)) GO TO 3
      IF((DEPTH.LE.2.0).AND.(DEPTH.GT.1.5)) GO TO 4
      IF((DEPTH.LE.2.5).AND.(DEPTH.GT.2.0)) GO TO 5
      IF((DEPTH.LT.3.0).AND.(DEPTH.GT.2.5)) GO TO 6
      IF((DEPTH.LE.3.5).AND.(DEPTH.GT.3.0)) GO TO 7
      IF((DEPTH.LE.4.0).AND.(DEPTH.GT.3.5)) GO TO 8
C
C     FOR DEPTHS LARGER THAN LAST SHEAR STRENGTH TAKE THE ARITHMETIC
C     AVERAGE OF THE LAST THREE AND CALL IT CONSTANT
C
      IF(DEPTH.GT.4.0) GO TO 9
C
C     FORMULAS FOR SHEAR STRENGTH FOLLOW
C     LINEAR VARIATION BETWEEN MEASURED POINTS IS ASSUMED
C
    1 SSS=SLOPE1*DEPTH
      GO TO 10
    2 SSS=SLOPE2*DEPTH+BINT2
      GO TO 10
    3 SSS=SLOPE3*DEPTH+BINT3
      GO TO 10
    4 SSS=SLOPE4*DEPTH+BINT4
      GO TO 10
    5 SSS=SLOPE5*DEPTH+BINT5
      GO TO 10
    6 SSS=SLOPE6*DEPTH+BINT6
      GO TO 10
    7 SSS=SLOPE7*DEPTH+BINT7
      GO TO 10
    8 SSS=SLOPE8*DEPTH+BINT8
      GO TO 10
    9 SSS=(SS30+SS305+SS40)/3.
C
C     SPS IS THE SHEAR STRENGTH IN POUNDS PER SQUARE FOOT
   10 SPS=SSS*144.
C     CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C     ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X SPS X DX
      CT=CFOOT*CNC
      WS(I)=CT*SPS*AREA(I)*DX
      AMASS1=(AMASS(I)*V(I)**2/2.)
      VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I))/(BMASS+DMASS(I)+AMASS(I))
      IF (VELOSQ.LE.0.0)GO TO 1000
```

```
      V(I+1)=SQRT(VELOSQ)
C
C
C     SECTION TO COMPUTE THE WORK DONE BY DRAG
C     APPROXIMATE AVERAGE VELOCITY OVER A SECTION BY NEGLECTING THE DRAG
C     FIRST TIME OVER THE SECTION, AS DONE ABOVE
      VAVG=(V(I)+V(I+1))/2.
      IF(I.EQ.1) VAVG=(V0+V(I+1))/2.
      WDRAG=.5*BWD*CD*AREA(I)*DX*VAVG**2
C
      VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I)-WDRAG)/(BMASS+DMASS(I)+AMAS
     2S(I))
      IF (VELOSQ.LE.0.0)GO TO 1000
      V(I+1)=SQRT(VELOSQ)
C
C     CALCULATE E AT NEXT SECTION
      E(I+1)=BMASS*V(I+1)**2/2.
C
C     CALCULATE ENERGY DISSIPATED BY ADDED MASS EFFECTS, EAM
      EAM=.5*(AMASS(I)*V(I+1)**2-2.0*AMASS1+DMASS(I)*V(I+1)**2)
C
C     COMPUTE PENETRATION DEPTH
      XXX=I*DX
C
C     PRINT THE SECTION, DEPTH OF PENETRATION, VELOCITY AT THE END OF
C     SECTION, SHEAR STRENGTH IN SECTION, BODY ENERGY AT END OF SECTION,
C     WORKDONE BY   SEDIMENT, ADDED MASS PLUS DISPLACED MASS, BUOYANCY,
C     AND DRAG
C
      WRITE(6,2600) I,XXX,V(I+1),SPS,E(I+1),WS(I),EAM,WB(I),WDRAG
 2000 CONTINUE
 1000 CONTINUE
 2050 FORMAT(I5)
 2060 FORMAT(' ',I3)
 2100 FORMAT(F5.1,8F5.2)
 2200 FORMAT('1',60X,'CYLINDER'//9X,'RADIUS = ',F7.3/9X,'LENGTH =',F7.3,
     2' FEET'/9X,'WEIGHT = ',F7.1,' LBS'/9X,'BULK WET DENSITY = ',F5.2,'
     3 SLUGS PER CUBIC FOOT'/9X,'DRAG COEFFICIENT = ',F5.2///)
 2300 FORMAT(' ',10X,'IMPACT VELOCITY EQUALS',F5.1///10X,'SEDIMENT SHEAR
     2 STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE'//15X,8F6.2//)
 2500 FORMAT('0',20X,'CONDITIONS AT THE END OF SECTION',19X,'WORK DONE I
     2N SECTION - FOOT POUNDS'///16X,'ITERATION',1X,'PENETRATION',4X,'VE
     3LOCITY',3X,'SHEAR',5X,'BODY ENERGY',6X,'STATIC',4X,'SEDIMENT',5X,'
     4BUOYANT',3X,'FORM DRAG'/17X,'SECTION',6X,'FEET',8X,'FT/SEC',2X,'ST
     5RENGTH PSF',4X,'FT-LBS',7X,'FORCES',4X,'INERTIA',6X,'FORCES',4X,'F
     6ORCES'//)
 2600 FORMAT(' ',16X,I3,3X,F12.2,7F12.3)
      STOP
```

```
IMPACT VELOCITY EQUALS  0.0
                                                                                   CYLINDER
SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE      RADIUS =    0.948
                                                                      LENGTH =   2.819 FEET
     0.42  1.08  1.48  1.57  2.44  2.72  2.69  2.93                   WEIGHT =    540.8 LBS
                                                                      BULK WET DENSITY =  2.72 SLUGS PER CUBIC FOOT
                                                                      DRAG COEFFICIENT =  0.68
               CONDITIONS AT THE END OF SECTION                          WORK DONE IN SECTION - FOOT POUNDS

   ITERATION PENETRATION     VELOCITY   SHEAR     BODY ENERGY     STATIC     SEDIMENT     BUOYANT    FORM DRAG
    SECTION      FEET         FT/SEC  STRENGTH PSF   FT-LBS        FORCES     INERTIA      FORCES     FORCES

       1         0.05         1.719      1.512      24.823        0.148       2.029       0.029      0.009
       2         0.10         2.253      4.536      42.655        3.502       5.037       0.285      0.391
       3         0.15         2.558      7.560      54.977        7.431       5.769       0.803      0.713
       4         0.20         2.720     10.584      62.196       12.135       5.251       1.431      1.002
       5         0.25         2.764     13.608      64.201       17.432       4.245       2.147      1.209
       6         0.30         2.703     16.632      61.391       23.199       2.404       2.936      1.309
       7         0.35         2.538     19.656      54.132       29.342      -0.120       3.787      1.288
       8         0.40         2.254     22.680      42.694       35.784      -3.139       4.693      1.138
       9         0.45         1.806     25.704      27.406       42.459      -6.634       5.645      0.856
      10         0.50         1.011     28.728       8.591       49.307     -10.522       6.638      0.429


IMPACT VELOCITY EQUALS  5.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

     0.51  0.75  1.08  1.88  2.04  1.96  2.38  2.70


               CONDITIONS AT THE END OF SECTION                          WORK DONE IN SECTION - FOOT POUNDS

   ITERATION PENETRATION     VELOCITY   SHEAR     BODY ENERGY     STATIC     SEDIMENT     BUOYANT    FORM DRAG
    SECTION      FEET         FT/SEC  STRENGTH PSF   FT-LBS        FORCES     INERTIA      FORCES     FORCES

       1         0.05         5.102      1.836     218.740        0.179      17.876       0.029      0.311
       2         0.10         5.149      5.508     224.576        4.253      14.112       0.285      2.550
       3         0.15         5.174      9.180     224.929        9.023      13.551       0.803      3.296
       4         0.20         5.127     12.852     220.922       14.735      11.073       1.431      3.816
       5         0.25         5.017     16.524     211.516       21.167       8.992       2.147      4.137
       6         0.30         4.846     20.196     197.349       28.170       5.839       2.936      4.260
       7         0.35         4.613     23.868     178.853       35.630       1.922       3.787      4.195
       8         0.40         4.311     27.540     156.157       43.452      -2.358       4.693      3.947
       9         0.45         3.927     31.212     129.592       51.557      -7.120       5.645      3.521
      10         0.50         3.440     34.884      99.472       59.873     -12.281       6.638      2.927
      11         0.55         2.804     38.556      66.082       68.336     -17.759       7.667      2.173
      12         0.60         1.881     42.228      29.734       76.836     -23.474       8.726      1.259
```

```
                                              CYLINDER
RADIUS =    0.948
LENGTH =  2.819 FEET
WEIGHT =    540.8 LBS
BULK WET DENSITY =  2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  0.68

 IMPACT VELOCITY EQUALS 10.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
      0.26  0.68  1.24  2.04  2.44  2.38  2.33  2.75

               CONDITIONS AT THE END OF SECTION                    WORK DONE IN SECTION - FOOT POUNDS

  ITERATION PENETRATION     VELOCITY   SHEAR      BODY ENERGY       STATIC      SEDIMENT      BUOYANT   FORM DRAG
   SECTION      FEET         FT/SEC  STRENGTH PSF    FT-LBS          FORCES      INERTIA       FORCES    FORCES

      1         0.05         9.761      0.936      800.685          0.091       65.433        0.029      1.190
      2         0.10         9.598      2.808      774.137          2.169       42.072        0.285      9.060
      3         0.15         9.420      4.680      745.666          4.600       38.963        0.803     11.143
      4         0.20         9.248      6.552      718.744          7.512       32.403        1.421     12.532
      5         0.25         9.059      8.424      689.585         10.791       29.786        2.147     13.472
      6         0.30         8.858     10.296      659.434         14.361       25.835        2.936     14.016
      7         0.35         8.650     12.168      628.845         18.164       21.306        3.787     14.349
      8         0.40         8.430     14.040      597.275         22.152       17.306        4.693     14.456
      9         0.45         8.195     15.912      564.357         26.224       13.180        5.645     14.346
     10         0.50         7.954     17.784      531.703         30.624        8.953        6.638     14.066
     11         0.55         7.697     19.656      497.909         34.828        4.629        7.667     13.638
     12         0.60         7.427     21.528      463.555         39.197        0.386        8.726     13.092
     13         0.65         7.142     23.400      428.710         43.570       -3.915        9.812     12.414
     14         0.70         6.842     25.272      393.435         47.930       -8.133       10.921     11.649
     15         0.75         6.525     27.144      357.782         52.240      -12.398       12.047     10.801
     16         0.80         6.187     29.016      321.700         56.900      -16.553       13.189      9.853
     17         0.85         5.829     30.888      285.580         60.655      -20.646       14.343      8.905
     18         0.90         5.444     32.760      249.072         64.685      -24.526       15.504      7.879
     19         0.95         5.016     34.632      211.486         68.566      -29.166       18.421      6.802
     20         1.00         4.570     37.966      175.499         74.375      -36.655       19.529      5.713
     21         1.05         3.987     43.614      133.578         86.340      -42.700       20.757      4.553
     22         1.10         3.195     49.562       85.813         98.323      -48.654       21.924      3.209
     23         1.15         1.961     55.710       32.306        110.297      -54.501       23.092      1.656
```

CYLINDER

```
RADIUS =    0.948
LENGTH =  2.819 FEET
WEIGHT =  [illegible] LBS
BULK WET DENSITY =  2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  0.63


 IMPACT VELOCITY EQUALS 15.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

      0.29  0.52  0.62  0.90  1.30  2.16  1.74  1.76

                 CONDITIONS AT THE END OF SECTION                       WORK DONE IN SECTION - FOOT POUNDS

     ITERATION PENETRATION  [illegible]     SHEAR     BODY ENERGY     STATIC      SEDIMENT      BUOYANT    FORM DRAG
      SECTION     FEET      [illegible] STRENGTH PSF    FT-LBS        FORCES      INERTIA       FORCES      FORCES

         1        0.05      [illegible]  [illegible]   1770.449    [illegible]     144.654       0.029     [illegible]
         2     [illegible]  [illegible]  [illegible]   1686.849    [illegible]  [illegible]   [illegible]     19.889
         3     [illegible]  [illegible]  [illegible]   1604.277    [illegible]  [illegible]   [illegible]  [illegible]
         4     [illegible]  [illegible]  [illegible]  [illegible]  [illegible]      64.781       1.421     [illegible]
         5     [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]   [illegible]  [illegible]
         6     [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]   [illegible]  [illegible]
         7     [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]   [illegible]  [illegible]
         8     [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]   [illegible]     30.180
         9     [illegible]  [illegible]  [illegible]   1179.795    [illegible]  [illegible]   [illegible]  [illegible]
        10     [illegible]  [illegible]  [illegible]  [illegible]  [illegible]      21.417    [illegible]  [illegible]
        11     [illegible]  [illegible]  [illegible]  [illegible]  [illegible]      15.074    [illegible]  [illegible]
        12     [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]   [illegible]     27.782
        13     [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]       9.812    [illegible]
        14     [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]   [illegible]  [illegible]
        15     [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]   [illegible]  [illegible]
        16     [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]   [illegible]  [illegible]
        17     [illegible]  [illegible]  [illegible]    698.326        67.653      -20.213      14.343        21.310
        18     [illegible]  [illegible]  [illegible]    643.224    [illegible]     -25.209      15.504        19.784
        19     [illegible]  [illegible]  [illegible]    588.017        78.477      -30.366    [illegible]     18.201
        20     [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]   [illegible]     16.715
        21     [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]      20.757        15.319
        22     [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]   [illegible]  [illegible]
        23     [illegible]  [illegible]  [illegible]    386.913    [illegible]  [illegible]   [illegible]     12.247
        24     [illegible]  [illegible]  [illegible]    329.030    [illegible]  [illegible]   [illegible]     10.575
        25     [illegible]  [illegible]  [illegible]    268.123       115.601      -61.968    [illegible]      8.814
        26     [illegible]  [illegible]  [illegible]    204.466    [illegible]     -64.932    [illegible]      6.962
        27     [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]   [illegible]      5.018
        28        1.40      [illegible]  [illegible]     68.414    [illegible]  [illegible]      28.930         2.966
```

```
                                         CYLINDER
RADIUS =    0.948
LENGTH =  2.819 FEET
WEIGHT =    540.8 LBS
BULK WET DENSITY =  2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  0.68


 IMPACT VELOCITY EQUALS 20.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

      0.68  0.73  1.74  2.30  2.45  2.60  2.58  2.90


                CONDITIONS AT THE END OF SECTION                       WORK DONE IN SECTION - FOOT POUNDS

      ITERATION PENETRATION     VELOCITY    SHEAR      BODY ENERGY      STATIC      SEDIMENT       BUOYANT      FORM DRAG
       SECTION      FEET         FT/SEC   STRENGTH PSF    FT-LBS         FORCES      INERTIA        FORCES       FORCES

          1          0.05         19.293        2.448     3127.998        0.239     255.626         0.029         4.705
          2          0.10         18.774        7.344     2962.121        5.670     151.921         0.285        35.034
          3          0.15         18.250       12.240     2793.098       12.031     134.934         0.303        42.237
          4          0.20         17.761       17.136     2651.059       19.647     107.355         1.431        46.639
          5          0.25         17.259       22.032     2503.344       28.223      95.071         2.147        49.304
          6          0.30         16.757       26.928     2355.854       37.560      79.358         2.936        50.659
          7          0.35         16.240       31.824     2221.654       47.506      62.639         3.787        51.100
          8          0.40         15.738       36.720     2081.797       57.936      48.667         4.693        50.793
          9          0.45         15.231       41.616     1954.502       68.742      34.981         5.645        49.837
         10          0.50         14.737       46.512     1825.073       79.831      21.599         6.638        48.430
         11          0.55         14.215       51.408     1693.117       91.115       8.547         7.667        46.665
         12          0.60         13.684       56.304     1571.555      102.514      -4.155         8.726        44.513
         13          0.65         13.141       61.200     1451.298      113.952     -16.483         9.912        42.082
         14          0.70         12.585       66.096     1330.913      125.355     -28.413        10.921        39.472
         15          0.75         12.012       70.992     1212.657      136.651     -39.932        12.047        36.575
         16          0.80         11.421       75.888     1096.134      147.769     -51.006        13.189        33.578
         17          0.85         10.807       80.784      981.526      158.636     -61.779        14.343        30.466
         18          0.90         10.165       85.680      868.394      169.180     -71.743        15.504        27.268
         19          0.95          9.473       90.576      755.732      179.326     -82.104        18.421        23.996
         20          1.00          8.816       97.935      653.104      193.896    -104.586        19.589        20.816
         21          1.05          8.095       98.655      550.646      195.321    -104.362        20.757        17.777
         22          1.10          7.305       99.375      447.407      196.747    -104.139        21.924        14.743
         23          1.15          6.420      100.095      344.385      198.172    -103.918        23.092        11.713
         24          1.20          5.395      100.815      244.591      199.598    -103.697        24.259         8.681
         25          1.25          4.125      101.535      142.998      201.023    -103.470        25.427         5.639
         26          1.30          2.227      102.255       41.679      202.449    -103.202        26.595         2.515
```

```
                                          CYLINDER
RADIUS =    0.948
LENGTH =  2.819 FEET
WEIGHT =    540.8 LBS
BULK WET DENSITY =  2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  0.68


  IMPACT VELOCITY EQUALS 20.0

 SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
       0.74  1.09  1.45  1.22  1.43  1.74  1.30  1.50


                CONDITIONS AT THE END OF SECTION
                                                                  WORK DONE IN SECTION - FOOT POUNDS
      ITERATION PENETRATION     VELOCITY   SHEAR       BODY ENERGY
       SECTION     FEET          FT/SEC  STRENGTH PSF    FT-LBS        STATIC     SEDIMENT       BUOYANT    FORM DRAG
                                                                       FORCES     INERTIA        FORCES     FORCES

          1         0.05         19.293      2.[illegible]     3127.979        0.260     255.624         0.029       4.705
          2         0.10         18.773      7.[illegible]     2951.698        6.170     151.337         0.285      35.031
          3         0.15         18.246     13.[illegible]     2797.852       13.093     134.746         0.803      42.225
          4         0.20         17.753     18.[illegible]     2648.565       21.280     105.900         1.431      46.[illegible]07
          5         0.25         17.245     23.[illegible]     2490.144       30.713      94.316         2.147      46.[illegible]40
          6         0.30         16.735     29.[illegible]     2353.664       40.974      78.229         2.936      50.[illegible]61
          7         0.35         16.228     34.[illegible]     2213.109       51.[illegible]93      61.1[illegible]         3.757      50.[illegible]32
          8         0.40         15.714     39.[illegible]     2075.150       63.[illegible]48      46.[illegible]40         4.693      50.[illegible]57
          9         0.45         15.193     45.[illegible]     1939.726       74.[illegible]08      32.470         5.645      4[illegible]59
         10         0.50         14.662     50.[illegible]     1806.667       86.[illegible]75      19.541         6.638      4[illegible].052
         11         0.55         14.121     55.[illegible]     1675.843       99.155       4.614         7.667      46.125
         12         0.60         13.568     61.[illegible]     1547.127      111.[illegible]50      -8.392         8.726      4[illegible]49
         13         0.65         13.001     66.[illegible]     1420.381      124.[illegible]07     -21.[illegible]         9.812      41.[illegible]34
         14         0.70         12.416     71.[illegible]     1295.472      136.[illegible]16     -34.[illegible]        10.921      3[illegible]30
         15         0.75         11.811     77.[illegible]     1172.273      148.[illegible]09     -46.001        12.047      35.481
         16         0.80         11.181     82.[illegible]     1050.677      160.[illegible]07     -57.687        13.189      32.225
         17         0.85         10.524     87.[illegible]2     930.737      172.[illegible]33     -68.049        14.343      29.050
         18         0.90          9.810     93.2[illegible]     812.089      184.107     -79.601        15.504      25.694
         19         0.95          9.086     98.[illegible]     693.831      195.149     -90.527        18.421      22.242
         20         1.00          8.333    106.[illegible]     573.557      211.130    -112.323        19.589      18.[illegible]64
         21         1.05          7.414    111.[illegible]     469.412      221.158    -116.267        20.757      15.[illegible]34
         22         1.10          6.467    116.[illegible]     371.453      231.137    -120.151        21.924      12.085
         23         1.15          5.229    121.7[illegible]5     259.745      241.115    -122.971        23.092       8.508
         24         1.20          3.524    126.[illegible]     134.367      251.0[illegible]4    -127.709        24.259       4.769
```

APPENDIX E: COMPUTATION OF A CYLINDER PENETRATING END-ON

```
C DYNAMIC PENETRATION OF AN OBJECT INTO THE OCEAN BOTTOM
C PROGRAM TO CALCULATE SECTION PROPERTIES OF A FLAT ENDED CYLINDER
C
C UNITS FEET/POUNDS/SLUGS/SECONDS/
C
C DX       INCREMENT SIZE
C
C BWD      BULK WET DENSITY OF SEDIMENT
C
C BMASS    OBJECT MASS
C
C AMASS()  ADDED MASS PLUS MASS OF DISPLACED SEDIMENT AT SECTION ( )
C
C DMASS( )CHANGE IN AMASS OVER SECTION INDICATED BY SUBSCRIPT
C
C AREA( )  PROJECTED AREA FOR SECTION ( )
C
C CNC      BEARING CAPACITY COEFFICIENT
C
  VOL( )   VOLUME OF SECTION ( )
C
C CFOOT    BEARING CAPACITY CONSTANT DEPENDS ON SHAPE OF AREA
C
C XXX      DEPTH OF PENETRATION
C
C V( )     VELOCITY OF OBJECT AT SECTION ( )
C
C WS( )    WORK DONE BY SEDIMENT IN SECTION ( )
C
C WT       WEIGHT OF OBJECT
C
C G        ACCELERATION OF GRAVITY
C
C SPS      SHEAR STRENGTH OF SEDIMENT
C
C RAD      RADIUS
C
C WDRAG    WORK DONE BY DRAG FORCES
C
C WB( )    WORK DONE BY BUOYANCY WHEN SUBMERGING TO SECTION ( )
C
C WBSUB( )WORK DONE BY SUBMERGED SECTION ( )
C
C US( )    WORK TO SUBMERGE SECTION ( )
C
```

```
C SUMSUB()WORK DONE BY SUBMERGED SECTIONS TO SECTION( )
C
C E( )    KINETIC ENERGY OF BODY AT SECTION( )
C
C
      DIMENSION AREA(100),VOL(100),AMASS(100),DMASS(100),SVOL(100),WS(10
     20).WB(100),WBSUB(100),US(100),SUMSUB(100),E(100),V(100)
      DATA PI/3.141593/,G/32.1725/,AREA/100*0.0/,VOL/100*0.0/,AMASS/100*
     20.0/,DMASS/100*0.0/,SVOL/100*0.0/,WS/100*0.0/,WB/100*0.0/,WBSUB/10
     30*0.0/,US/100*0.0/,SUMSUB/100*0.0/,E/100*0.0/,V/100*0.0/
C
C
C
C     INPUT DATA ON OBJECT
C     OBJECT  CYLINDER IMPACTING WITH FLAT END
      RAD=.94791
      WT=561.75
      BWD=87.402/G
      CFOOT=1.3
      CNC=5.7
C     COHESION OR SHEAR STRENGTH IN PSI EQUALS .3 FOR PROGRAM CHECKOUT
      COH=43.2
C
C     FOR A CYLINDER END ON USE A DRAG COEFFICIENT OF .9
      CD=0.9
C
C
C     SET INCREMENT
      DX=.05
C
C
C
C     CALCULATE THE SECTION PROPERTIES,AVERAGE PROJECTED AREA,VOLUME
C     FIND AREA AT MIDPOINT OF EACH SECTION
C     Y=DISTANCE ABOVE BOTTOM OF CYLINDER
      Y=DX/2.
      YMAX=2.777
      Z=YMAX/DX
      N=Z+1.
C     THE ONE ACCOUNTS FOR INTEGER TRUNCATION IN THIS PROBLEM
      AREA(1)=PI*(RAD**2)
      DO 100 I=2,N
      AREA(I)=AREA(1)
  100 CONTINUE
C     FOR THIS ANALYSIS THE AREA IS CONSTANT FOR THE REMAINING
C     PENETRATION THEREFORE SET SUCCEEDING AREAS AS FOLLOWS
      DO 200 I=N,100
      AREA(I)=AREA(N)
```

```
C     PRINT,AREA(I)
  200 CONTINUE
C
C     COMPUTE THE VOLUME OF EACH SECTION
C     VOLUME EQUALS AVERAGE AREA TIMES SECTION HEIGHT
C
      DO 300 I=1,100
      VOL(I)=AREA(I)*DX
  300 CONTINUE
C
C     CHECK VOLUME CALCULATIONS
      HAFVOL=PI*RAD**2*YMAX
      CVOL=VOL(1)
      DO 350 I=2,N
      CVOL=CVOL+VOL(I)
  350 CONTINUE
C
      ERROR=CVOL-HAFVOL
C     PRINT,CVOL,HAFVOL,ERROR
C
C
C
C     CALCULATE ADDED MASS, DISPLACED MASS AND CHANGE IN ADDED MASS PLUS
C     DISPLACED MASS FROM SECTION TO SECTION.
C     APPROXIMATE BY USING ONE HALF OF A CIRCULAR DISK, AMASS BECOMES
C     CONSTANT WHEN MAX AREA HAS BEEN REACHED.
C
      SUMVOL=0.0
      K=N+1
      DO 400 I=2,K
C     SEE PAGE 421 OF SAUNDERS FOR FORMULAS BELOW
      AMASS(I-1)=BWD*(4./3.)*RAD**3
C
C     SINCE SEPARATION OCCURS AT IMPACT AMASS REMAINS CONSTANT AND THERE
C     IS NO CONTRIBUTION FROM THE DISPLACED MASS
  400 CONTINUE
C
C     AMASS REMAINS THE SAME AFTER MAX AREA
C
      DO 450 I=N,100
      AMASS(I)=AMASS(N)
C     PRINT,AMASS(N)
  450 CONTINUE
C
C     COMPUTE CHANGE IN AMASS FROM SECTION TO SECTION
      DMASS(1)=0.0
      DO 500 I=2,N
      DMASS(I)=AMASS(I)-AMASS(I-1)
```

```
C     PRINT,DMASS(N)
  500 CONTINUE
C
C
C     CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C     PER SECTION IF THE SHEAR STRENGTH IS CONSTANT FOR PROGRAM CHECK
C     ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X COHESIONX DX
      CT=CFOOT*CNC
      DO 600 I=1,100
      WS(I)=CT*COH*AREA(I)*DX
  600 CONTINUE
C
C
C
C     CALCULATE WORK DONE BY BUOYANCY
C
C
      GAMMA=BWD*G
      WB(1)=(GAMMA*AREA(1)*DX**2)/2.
      SUMSUB(1)=2,0*WB(1)
      DO 700 I=2,N
C
C     WORK TO SUBMERGE SECTION
      US(I)=(GAMMA*AREA(I)*DX**2)/2.
C
C     WORK TO CONTINUE SECTION AFTER SUBMERGING
      WBSUB(I)=2.0*US(I)
C
C     TOTAL WORK OF THE SUBMERGED SECTIONS
      SUMSUB(I)=SUMSUB(I-1)+WBSUB(I)
C
C     TOTAL WORK DONE SUBMERGING SECTION PLUS THOSE ALREADY SUBMERGED
      WB(I)=US(I)+SUMSUB(I-1)
  700 CONTINUE
C
C     AFTER ALL SECTIONS ARE SUBMERGED WORK BECOMES CONSTANT EQUAL TO
C     SUMSUB(N) PLUS WBSUB(N) FOR EACH FURTHUR INCREMENT
C     THIS ASSUMES A CAVITY IS FORMED AFTER THE OBJECT PENETRATES PAST
C     ITS MAXIMUM DIMENSION
C
      DO 760 I=N,100
      WB(I)=SUMSUB(N)+(I-(N-1))*WBSUB(N)
C     PRINT,WB(I)
  760 CONTINUE
C
C     CHECK WORK TO SUBMERGE
C
      CWB=WB(1)
```

```
      DO 8CO  I=2,N
      CWB=CWB+WB(I)
  800 CONTINUE
C     PRINT,CWB
C
C     ACTUAL WORK BY INTEGRATION IS
C
      X=N*DX
      AWB=(GAMMA*PI*RAD**2*X**2/2.)
C     PRINT,AWB,X
C
C
C
C
C
C     PROGRAM TO COMPUTE PENETRATION DEPTH FOLLOWS
C
C
C     BE ABLE TO DO NNN DIFFERENT VELOCITIES AND SHEAR STRENGTHS
      READ(5,2C50) NNN
      WRITE(6,2060)NNN
C
      DO 1000 J=1,NNN
      WRITE(6,2200) RAD,WT,BWD,CD
C
C     READ IN THE VELOCITIES AND SHEAR STRENGTHS
      READ(5,2100) VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40
      WRITE(6,2300)VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40
      WRITE(6,2500)
C
C
C     CALCULATE ORIGINAL ENERGY OF BODY AT INTERFACE
      BMASS=WT/G
      E(1)=BMASS*VO**2/2.
C
C     CALCULATE POTENTIAL ENERGY FOR EACH INCREMENT
      EP=WT*DX
C
C
C     COMPUTE SLOPE OF SHEAR STRENGTH VARIATIONS
C
      SLOPE1=SS05/.5
      BINT1=C.0
C
      SLOPE2=(SS10-SS05)/.5
      BINT2=-SLOPE2*.5+SS05
C
      SLOPE3=(SS105-SS10)/.5
      BINT3=-SLOPE3*1.+SS10
C
```

```
      SLOPE4=(SS20-SS105)/.5
      BINT4=-SLOPE4*1.5+SS105
C
      SLOPE5=(SS205-SS20)/.5
      BINT5=-SLOPE5*2.0+SS20
C
      SLOPE6=(SS30-SS205)/.5
      BINT6=-SLOPE6*2.5+SS205
C
      SLOPE7=(SS305-SS30)/.5
      BINT7=-SLOPE7*3.+SS30
C
      SLOPE8=(SS40-SS305)/.5
      BINT8=-SLOPE8*3.5+SS305
C
C
C     VELOCITY OF SEDIMENT AT INTERFACE IS ALWAYS 0 AT INSTANT OF IMPACT
      V(1)=0.0
      DO 2000 I=1,100
C     SECTION TO COMPUTE SHEAR STRENGTH
C     NOTE THAT THE SHEAR STRENGTH IS COMPUTED IN INCHES THEN CONVERTED
C     TO POUNDS PER SQUARE FOOT FOR THE CALCULATION
C
C     FOR THE CYLINDER TAKE THE DEPTH FOR SHEAR STRENGTH TO BE THE
C     PENETRATION DEPTH
      DEPTH=I*DX-Y
C
C     CONVERT THE DEPTH TO INCHES FOR EASY COMPARISON WITH  DATA
      DEPTHI=DEPTH*12.
C
C     SELECT PROPER DEPTH
      IF(DEPTH.LE..5) GO TO 1
      IF((DEPTH.LE.1.0).AND.(DEPTH.GT.0.5)) GO TO 2
      IF((DEPTH.LE.1.5).AND.(DEPTH.GT.1.0)) GO TO 3
      IF((DEPTH.LE.2.0).AND.(DEPTH.GT.1.5)) GO TO 4
      IF((DEPTH.LE.2.5).AND.(DEPTH.GT.2.0)) GO TO 5
      IF((DEPTH.LT.3.0).AND.(DEPTH.GT.2.5)) GO TO 6
      IF((DEPTH.LE.3.5).AND.(DEPTH.GT.3.0)) GO TO 7
      IF((DEPTH.LE.4.0).AND.(DEPTH.GT.3.5)) GO TO 8
C
C     FOR DEPTHS LARGER THAN LAST SHEAR STRENGTH TAKE THE ARITHMETIC
C     AVERAGE OF THE LAST THREE AND CALL IT CONSTANT
C
      IF(DEPTH.GT.4.0) GO TO 9
C
C     FORMULAS FOR SHEAR STRENGTH FOLLOW
C     LINEAR VARIATION BETWEEN MEASURED POINTS IS ASSUMED
C
```

```
    1 SSS=SLOPE1*DEPTH
      GO TO 10
    2 SSS=SLOPE2*DEPTH+BINT2
      GO TO 10
    3 SSS=SLOPE3*DEPTH+BINT3
      GO TO 10
    4 SSS=SLOPE4*DEPTH+BINT4
      GO TO 10
    5 SSS=SLOPE5*DEPTH+BINT5
      GO TO 10
    6 SSS=SLOPE6*DEPTH+BINT6
      GO TO 10
    7 SSS=SLOPE7*DEPTH+BINT7
      GO TO 10
    8 SSS=SLOPE8*DEPTH+BINT8
      GO TO 10
C
    9 SSS=(SS30+SS305+SS40)/3.
C
C     SPS IS THE SHEAR STRENGTH IN POUNDS PER SQUARE FOOT
   10 SPS=SSS*144.
C     CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C     ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X SPS X DX
      CT=CFOOT*CNC
      WS(I)=CT*SPS*AREA(I)*DX
      AMASS1=(AMASS(I)*V(I)**2/2.)
      VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I))/(BMASS+DMASS(I)+AMASS(I))
      IF (VELOSQ.LE.0.0)GO TO 1000
      V(I+1)=SQRT(VELOSQ)
C
C
C     SECTION TO COMPUTE THE WORK DONE BY DRAG
C     APPROXIMATE AVERAGE VELOCITY OVER A SECTION BY NEGLECTING THE DRAG
C     FIRST TIME OVER THE SECTION, AS DONE ABOVE
      VAVG=(V(I)+V(I+1))/2.
      IF(I.EQ.1) VAVG=(VO+V(I+1))/2.
      WDRAG=.5*BWD*CD*AREA(I)*DX*VAVG**2
C
      VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I)-WDRAG)/(BMASS+DMASS(I)+AMAS
     2S(I))
      IF (VELOSQ.LE.0.0)GO TO 1000
      V(I+1)=SQRT(VELOSQ)
C
C     CALCULATE E AT NEXT SECTION
      E(I+1)=BMASS*V(I+1)**2/2.
C
C     CALCULATE ENERGY DISSIPATED BY ADDED MASS EFFECTS, EAM
      EAM=.5*(AMASS(I)*V(I+1)**2-2.0*AMASS1+DMASS(I)*V(I+1)**2)
```

```
C
C     COMPUTE PENETRATION DEPTH
      XXX=I*DX
C
C     PRINT THE SECTION, DEPTH OF PENETRATION, VELOCITY AT THE END OF
C     SECTION, SHEAR STRENGTH IN SECTION. BODY ENERGY AT END OF SECTION,
C     WORK DONE BY   SEDIMENT, ADDED MASS PLUS DISPLACED MASS, BUOYANCY,
C     AND DRAG
C
      WRITE(6,2600) I,XXX,V(I+1),SPS,E(I+1),WS(I),EAM,WB(I),WDRAG
 2000 CONTINUE
 1000 CONTINUE
 2050 FORMAT(I5)
 2060 FORMAT(' ',I3)
 2100 FORMAT(F5.1,8F5.2)
 2200 FORMAT('1',60X,'CYLINDER  FLAT END IMPACTING'//9X,'RADIUS = ',
    2F7.3/9X,'WEIGHT = ',F7.1,' LBS'/
    39X,'BULK WET DENSITY = ',F5.2,'SLUGS PER CUBIC FOOT'/9X,'DRAG
    4 COEFFICIENT = ',F5.2///)
 2300 FORMAT(' ',10X,'IMPACT VELOCITY EQUALS',F5.1///10X,'SEDIMENT SHEAR
    2 STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE'//15X,8F6.2//)
 2500 FORMAT('0',28X,'CONDITIONS AT THE END OF SECTION',10X,'WORK DONE I
    2N SECTION - FOOT POUNDS'///16X,'ITERATION',1X,'PENETRATION',4X,'VE
    3LOCITY',3X,'SHEAR',4X,'BODY ENERGY',6X,'STATIC',4X,'SEDIMENT',5X,'
    4BUOYANT',3X,'FORM DRAG'/17X,'SECTION',6X,'FEET',8X,'FT/SEC',2X,'ST
    5RENGTH PSF',4X,'FT-LBS',7X,'FORCES',4X,'INERTIA',6X,'FORCES',4X,'F
    6ORCES'//)
 2600 FORMAT(' ',16X,I3,3X,F12.2,7F12.3)
      STOP
      END
```

```
                                                         CYLINDER  FLAT END IMPACTING
RADIUS =    0.948
WEIGHT =    561.8 LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG       COEFFICIENT =  0.90


  IMPACT VELOCITY EQUALS  5.0

 SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

       0.30  0.61  1.39  2.09  2.44  2.72  2.70  2.90

                  CONDITIONS AT THE END OF SECTION                        WORK DONE IN SECTION - FOOT POUNDS

         ITERATION PENETRATION    VELOCITY   SHEAR      BODY ENERGY      STATIC     SEDIMENT     BUOYANT    FORM DRAG
          SECTION      FEET        FT/SEC  STRENGTH PSF    FT-LBS        FORCES     INERTIA      FORCES     FORCES

            1          0.05        4.829      2.160       203.529        2.259      35.974       0.308       4.203
            2          0.10        4.990      6.480       217.359        6.777       2.431       0.925       4.193
            3          0.15        5.094     10.800       226.540       11.295       1.626       1.542       4.423
            4          0.20        5.147     15.120       231.278       15.813       0.834       2.159       4.562
            5          0.25        5.150     19.440       231.500       20.331       0.055       2.776       4.613
            6          0.30        5.106     23.760       227.569       24.850      -0.710       3.392       4.576
            7          0.35        5.012     28.080       219.210       29.368      -1.463       4.009       4.453
            8          0.40        4.867     32.400       206.822       33.886      -2.203       4.626       4.246
            9          0.45        4.668     36.720       190.236       38.404      -2.930       5.243       3.956
           10          0.50        4.408     41.040       169.604       42.922      -3.646       5.860       3.584
           11          0.55        4.074     45.360       144.929       47.515      -4.360       6.476       3.131
           12          0.60        3.649     49.680       116.216       52.184      -5.073       7.093       2.596
           13          0.65        3.093     54.000        83.546       56.853      -5.774       7.710       1.979
           14          0.70        2.319     58.320        46.962       61.521      -6.462       8.327       1.276
           15          0.75        0.870     63.228         6.602       66.190      -7.131       8.944       0.445
```

```
                                                     CYLINDER  FLAT END IMPACTING
RADIUS =    0.948
WEIGHT =    561.8 LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG       COEFFICIENT =  0.90


 IMPACT VELOCITY EQUALS 10.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

      0.36  0.54  1.04  1.36  2.44  2.78  2.80  2.96


                CONDITIONS AT THE END OF SECTION                        WORK DONE IN SECTION - FOOT POUNDS

     ITERATION PENETRATION      VELOCITY   SHEAR      BODY ENERGY       STATIC     SEDIMENT       BUOYANT    FORM DRAG
      SECTION      FEET          FT/SEC  STRENGTH PSF    FT-LBS         FORCES     INERTIA        FORCES     FORCES

         1           0.05         9.266      2.592      749.511          2.711     132.423         0.308      16.151
         2           0.10         9.287      7.776      752.938          8.133       0.609         0.925      14.973
         3           0.15         9.276     12.960      751.259         13.554      -0.300         1.542      14.990
         4           0.20         9.235     18.144      744.409         18.976      -1.194         2.159      14.906
         5           0.25         9.162     23.328      733.764         24.398      -2.073         2.776      14.722
         6           0.30         9.057     28.512      716.127         29.819      -2.938         3.392      14.439
         7           0.35         8.920     33.696      694.702         35.241      -3.778         4.009      14.063
         8           0.40         8.751     38.880      668.537         40.663      -4.623         4.626      13.585
         9           0.45         8.547     44.064      637.724         46.085      -5.444         5.243      13.017
        10           0.50         8.306     49.248      602.340         51.506      -6.252         5.860      12.357
        11           0.55         8.035     53.136      563.605         55.573      -6.944         6.476      11.618
        12           0.60         7.738     55.728      522.716         58.283      -7.225         7.093      10.824
        13           0.65         7.413     58.320      479.709         60.994      -7.609         7.710       9.987
        14           0.70         7.056     60.912      434.622         63.705      -7.977         8.327       9.103
        15           0.75         6.662     63.504      387.440         66.416      -8.328         8.944       8.183
        16           0.80         6.225     66.096      338.346         69.127      -8.683         9.560       7.227
        17           0.85         5.736     68.583      287.225         71.838      -9.033        10.177       6.226
        18           0.90         5.179     71.280      234.160         74.549      -9.376        10.794       5.185
        19           0.95         4.530     73.872      179.187         77.260      -9.713        11.411       4.103
        20           1.00         3.743     76.464      122.340         79.970     -10.044        12.028       2.981
        21           1.05         2.657     81.360       61.634         85.091     -10.726        12.644       1.785
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                                        CYLINDER  FLAT END IMPACTING
RADIUS =    0.948
WEIGHT =    561.8 LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG      COEFFICIENT =  0.90


 IMPACT VELOCITY EQUALS 15.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
     0.52  0.78  1.38  2.12  2.38  2.01  2.11  1.97


                 CONDITIONS AT THE END OF SECTION                  WORK DONE IN SECTION - FOOT POUNDS

ITERATION PENETRATION    VELOCITY   SHEAR       BODY ENERGY     STATIC     SEDIMENT      BUOYANT    FORM DRAG
 SECTION      FEET        FT/SEC  STRENGTH PSF    FT-LBS        FORCES     INERTIA       FORCES     FORCES

     1         0.05      13.735       3.744     1659.988       3.916     293.131        0.308     36.057
     2         0.10      13.723      11.232     1644.113      11.747      -2.628        0.925     32.919
     3         0.15      13.682    [illegible]  1622.369      19.578  [illegible]       1.542  [illegible]
     4         0.20      13.512    [illegible]  1592.871      27.410  [illegible]       2.159     32.052
     5         0.25    [illegible] [illegible] [illegible]     35.241  [illegible]       2.776     31.418
     6         0.30      13.192    [illegible] [illegible]     43.073      -7.362       3.392  [illegible]
     7         0.35      12.972    [illegible] [illegible]     50.904      -8.497       4.009  [illegible]
     8         0.40    [illegible] [illegible] [illegible]     58.735      -9.612       4.626  [illegible]
     9         0.45    [illegible] [illegible] [illegible]     66.567     -10.709       5.243  [illegible]
    10         0.50      12.143    [illegible] [illegible]     74.398     -11.786       5.860  [illegible]
    11         0.55      11.803    [illegible] [illegible]     80.272     -12.555       6.476  [illegible]
    12         0.60    [illegible] [illegible] [illegible]     84.187     -13.018       7.093  [illegible]
    13         0.65    [illegible] [illegible] [illegible]     88.103     -13.475       7.710  [illegible]
    14         0.70      10.635    [illegible] [illegible]     92.019     -13.923       8.327     20.463
    15         0.75    [illegible] [illegible] [illegible]     95.934     -14.364       8.944  [illegible]
    16         0.80    [illegible] [illegible]  [illegible]    99.850     -14.797       9.560     17.220
    17         0.85    [illegible] [illegible]   736.284      103.766     -15.223      10.177     15.525
    18         0.90       8.614    [illegible]   647.756      107.681     -15.642      10.794     13.762
    19         0.95    [illegible] [illegible]   555.897      111.597     -16.054      11.411     11.992
    20         1.00    [illegible] [illegible]   463.749      115.513     -16.459      12.028     10.154
    21         1.05       6.477     116.646   [illegible]     121.998     -17.237      12.644      8.246
    22         1.10       5.400    [illegible]   263.153      131.025     -18.383      13.261      6.223
    23         1.15       4.169     133.920      151.752      140.061     -19.507      13.878      4.055
    24         1.20       2.007     142.560       35.179      149.097     -20.598      14.495      1.667
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                                                       CYLINDER  FLAT END IMPACTING
RADIUS =     0.948
WEIGHT =     561.8 LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG       COEFFICIENT =  0.90

  IMPACT VELOCITY EQUALS 20.0

 SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

      0.69  1.04  1.43  1.06  1.97  1.57  1.65  1.76

                 CONDITIONS AT THE END OF SECTION                          WORK DONE IN SECTION - FOOT POUNDS

      ITERATION PENETRATION    VELOCITY   SHEAR       BODY ENERGY      STATIC     SEDIMENT      BUOYANT     FORM DRAG
       SECTION      FEET        FT/SEC  STRENGTH PSF      FT-LBS        FORCES     INERTIA       FORCES      FORCES

          1          0.05       18.328       4.969      2932.592        5.196     518.167        0.308       63.928
          2          0.10       18.204      14.904      2893.084       15.587      -6.981        0.925       58.057
          3          0.15       18.052      24.841      2844.961       25.979      -8.503        1.542       57.184
          4          0.20       17.872      34.777      2788.373       36.371      -9.993        2.159       56.140
          5          0.25       17.652      44.713      2723.455       46.762     -11.470        2.776       54.929
          6          0.30       17.424      54.649      2650.352       57.154     -12.917        3.392       53.553
          7          0.35       17.155      64.584      2569.197       67.546     -14.340        4.009       52.016
          8          0.40       16.855      74.520      2480.131       77.937     -15.737        4.626       50.319
          9          0.45       16.522      84.454      2383.289       88.329     -17.111        5.243       48.466
         10          0.50       16.156      94.390      2273.795       98.720     -18.463        5.860       46.459
         11          0.55       15.762     101.381      2168.941      106.552     -19.410        6.476       44.322
         12          0.60       15.346     106.920      2055.971      111.823     -19.961        7.093       42.101
         13          0.65       14.907     111.960      1939.937      117.094     -20.502        7.710       39.818
         14          0.70       14.442     117.000      1820.391      122.365     -21.034        8.327       37.474
         15          0.75       13.950     122.040      1698.885      127.636     -21.557        8.944       35.071
         16          0.80       13.427     127.080      1573.967      132.907     -22.072        9.560       32.609
         17          0.85       12.871     132.120      1446.187      138.179     -22.578       10.177       30.089
         18          0.90       12.276     137.160      1315.593      143.450     -23.075       10.794       27.513
         19          0.95       11.637     142.200      1182.232      148.721     -23.564       11.411       24.980
         20          1.00       10.947     147.240      1046.152      153.992     -24.044       12.028       22.192
         21          1.05       10.194     152.568       907.145      159.564     -24.562       12.644       19.447
         22          1.10        9.361     158.184       765.008      165.438     -25.115       13.261       16.640
         23          1.15        8.426     163.800       619.795      171.311     -25.658       13.878       13.769
         24          1.20        7.349     169.416       471.562      177.185     -26.192       14.495       10.832
         25          1.25        6.058     175.032       320.267      183.058     -26.715       15.112        7.826
         26          1.30        4.364     180.648       166.286      188.932     -27.225       15.728        4.733
         27          1.35        1.049     186.264         9.614      194.805     -27.683       16.345        1.292
```

```
IMPACT VELOCITY EQUALS  0.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE              CYLINDER  FLAT END IMPACTING
      0.21  0.35  0.52  1.10  2.30  2.78  2.56  3.10                  RADIUS =     0.948
                                                                      WEIGHT =     5[illegible].8 LBS
                                                                      BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
                CONDITIONS AT THE END OF SECTION                      DRAG        COEFFICIENT =  0.90
                                                                         WORK DONE IN SECTION - FOOT POUNDS
 ITERATION PENETRATION    VELOCITY   SHEAR       BODY ENERGY
 SECTION       FEET       FT/SEC   STRENGTH PSF     FT-LBS        STATIC       SEDIMENT       BUOYANT      FORM DRAG
                                                                   FORCES       INERTIA        FORCES       FORCES
   1           0.05        1.594      1.512         22.170         1.531        3.917          0.308        0.110
   2           0.10        2.159      4.5[illegible]     40.702         4.744        3.274          0.925        0.612
   3           0.15        2.527      7.5[illegible]     53.731         7.907        2.35[illegible]      1.542        0.955
   4           0.20        2.777     10.5[illegible]     67.320        11.069        2.048          2.159        1.223
   5           0.25        2.94[illegible]    13.6[illegible]     75.527        14.2[illegible]2       1.450          2.776        1.422
   6           0.30        3.[illegible]3[illegible]   16.6[illegible]     80.41[illegible]      17.3[illegible]5       0.[illegible]63        3.392        1.553
   7           0.35        3.[illegible]6[illegible]   19.6[illegible]     8[illegible].02[illegible]     20.557        0.[illegible]86        4.009        1.619
   8           0.40        3.[illegible]3[illegible]   22.6[illegible]     80.432        23.7[illegible]0      -0.282          4.626        1.619
   9           0.45        2.[illegible]4[illegible]   25.7[illegible]     7[illegible].678       26.8[illegible]3      -0.[illegible]40       5.243        1.556
  10           0.50        2.[illegible]8[illegible]   28.7[illegible]     6[illegible].820       30.0[illegible]5      -1.[illegible]89       5.860        1.429
  11           0.55        2.[illegible]53    31.2[illegible]     57.354        32.5[illegible]1      -1.[illegible]4[illegible]     6.476        1.246
  12           0.60        2.[illegible]64    33.2[illegible]     44.768        34.7[illegible]9      -2.[illegible]24       7.093        1.014
  13           0.65        1.[illegible]57    35.2[illegible]     30.100        36.8[illegible]8      -2.[illegible]92       7.710        0.7[illegible]0
  14           0.70        1.[illegible]38    37.29[illegible]    13.389        39.006       -2.[illegible]53       8.327        0.418


IMPACT VELOCITY EQUALS  5.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
      0.87  1.04  1.04  1.41  1.13  1.48  1.87  1.76


                CONDITIONS AT THE END OF SECTION
                                                                         WORK DONE IN SECTION - FOOT POUNDS
 ITERATION PENETRATION    VELOCITY   SHEAR       BODY ENERGY
 SECTION       FEET       FT/SEC   STRENGTH PSF     FT-LBS        STATIC       SEDIMENT       BUOYANT      FORM DRAG
                                                                   FORCES       INERTIA        FORCES       FURCES
   1           0.05        4.786      6.264        193.982         6.551       35.335          0.308        4.167
   2           0.10        4.[illegible]1    18.792        20[illegible].951       19.654        0.524          0.925        4.015
   3           0.15        [illegible].7[illegible]8   31.320        19[illegible].303       32.756       -1.527          1.542        3.959
   4           0.20        4.468     [illegible]3.84[illegible]   17[illegible].250       45.[illegible]59      -3.544          2.159        3.671
   5           0.25        4.047     56.376        14[illegible].973       59.961       -5.527          2.776        3.155
   6           0.30        3.3[illegible]6    6[illegible].904        100.667        72.064       -7.475          3.392        2.411
   7           0.35        2.333     81.432         47.537        85.166       -9.389          4.009        1.431
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                                                  CYLINDER  FLAT END IMPACTING
RADIUS =     0.948
WEIGHT =     561.8 LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG        COEFFICIENT =  0.90

 IMPACT VELOCITY EQUALS 10.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
      0.24  0.33  0.71  0.87  1.74  1.74  1.79  1.81

                 CONDITIONS AT THE END OF SECTION                      WORK DONE IN SECTION - FOOT POUNDS

   ITERATION PENETRATION     VELOCITY    SHEAR     BODY ENERGY      STATIC      SEDIMENT       BUOYANT     FORM DRAG
    SECTION     FEET          FT/SEC   STRENGTH PSF   FT-LBS        FORCES      INERTIA        FORCES      FORCES

       1         0.05       [illegible]     1.728      750.272       1.827      132.568        0.308       16.159
       2         0.10       [illegible] [illegible]    755.991       5.422        1.010        0.925       15.010
       3         0.15       [illegible] [illegible]    753.048  [illegible]       0.363        1.542       15.088
       4         0.20       [illegible] [illegible] [illegible]     12.651       -0.273        2.159       15.093
       5         0.25       [illegible] [illegible]    751.422      16.265       -0.898        2.776       15.027
       6         0.30       [illegible] [illegible]    742.858      19.880       -1.513        3.392       14.892
       7         0.35       [illegible] [illegible]    730.873  [illegible]      -2.118        4.009       14.687
       8         0.40       [illegible] [illegible]    713.523  [illegible]      -2.712        4.626       14.414
       9         0.45       [illegible] [illegible] [illegible]     30.723       -3.297        5.243       14.075
      10         0.50       [illegible] [illegible] [illegible] [illegible]      -3.871        5.860       13.671
      11         0.55       [illegible] [illegible]    650.800      36.842       -4.268        6.476       13.212
      12         0.60       [illegible] [illegible] [illegible] [illegible]      -4.490        7.093       12.718
      13         0.65       [illegible] [illegible]    593.741  [illegible]      -4.708        7.710       12.199
      14         0.70       [illegible] [illegible]    570.879      40.889       -4.923        8.327       11.655
      15         0.75       [illegible] [illegible] [illegible]     42.244       -5.134        8.944       11.088
      16         0.80       [illegible] [illegible] [illegible]     43.600       -5.341        9.560       10.497
      17         0.85       [illegible] [illegible]    480.212      44.955       -5.545       10.177        9.883
      18         0.90       [illegible] [illegible]    447.695      46.310       -5.746       10.794        9.246
      19         0.95       [illegible] [illegible]    414.061      47.666       -5.943       11.411        8.586
      20         1.00       [illegible] [illegible]    379.331      49.021       -6.137       12.028        7.904
      21         1.05       [illegible] [illegible]    341.683      52.560       -6.652       12.644        7.182
      22         1.10       [illegible] [illegible]    299.327      58.283       -7.484       13.261        6.383
      23         1.15       [illegible] [illegible]    252.341      64.006       -8.302       13.878        5.490
      24         1.20       [illegible] [illegible]    200.807      69.729       -9.106       14.495        4.503
      25         1.25       [illegible] [illegible]    144.802      75.452       -9.896       15.112        3.424
      26         1.30       [illegible] [illegible]     84.410      81.175      -10.671       15.728        2.247
      27         1.35         1.504     [illegible]     19.749      86.899      -11.425       16.345        0.930
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                                               CYLINDER  FLAT END IMPACTING
RADIUS =     0.948
WEIGHT =     551.8 LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG        COEFFICIENT =  0.90


  IMPACT VELOCITY EQUALS 15.0

 SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

       0.66  1.00  1.07  0.87  1.20  1.57  1.43  1.50


                  CONDITIONS AT THE END OF SECTION                   WORK DONE IN SECTION - FOOT POUNDS

      ITERATION PENETRATION      VELOCITY    SHEAR      BODY ENERGY        STATIC     SEDIMENT        BUOYANT    FORM DRAG
       SECTION      FEET          FT/SEC   STRENGTH PSF    FT-LBS          FORCES     INERTIA         FORCES     FORCES

          1          0.05        13.781       4.772     1658.100           4.970     292.974          0.308       36.048
          2          0.10        13.706      14.256     1640.575          14.910      -3.096          0.925       32.873
          3          0.15        13.599      23.740     1614.448          24.850      -4.616          1.542       32.439
          4          0.20        13.422      33.224     1579.964          34.789      -6.111          2.159       31.833
          5          0.25        13.262      42.708     1539.265          44.729      -7.580          2.776       31.061
          6          0.30        13.046      52.272     1485.891          54.669      -9.025          3.392       30.124
          7          0.35        12.764      61.776     1424.779          64.609     -10.445          4.009       29.026
          8          0.40        12.470      71.260     1358.764          74.549     -11.841          4.626       27.768
          9          0.45        12.152      80.744     1281.379          84.488     -13.214          5.243       26.354
         10          0.50        11.777      90.219     1202.556          94.428     -14.564          5.860       24.786
         11          0.55        11.299      97.470     1114.652         101.558     -15.532          6.476       23.088
         12          0.60        10.817     102.314     1025.391         107.079     -16.125          7.093       21.301
         13          0.65        10.315     107.250      921.229         112.199     -16.708          7.710       19.447
         14          0.70         9.756     112.176      831.022         117.320     -17.282          8.327       17.528
         15          0.75         9.144     117.072      730.025         122.441     -17.845          8.944       15.545
         16          0.80         8.447     121.968      625.993         127.561     -18.399          9.560       13.497
         17          0.85         7.709     126.864      518.679         132.682     -18.944         10.177       11.385
         18          0.90         6.850     131.760      401.438         137.802     -19.479         10.794        9.211
         19          0.95         5.815     136.656      295.223         142.923     -20.004         11.411        6.972
         20          1.00         4.529     141.552      179.097         148.043     -20.519         12.028        4.660
         21          1.05         2.652     144.504       61.867         151.130     -20.714         12.644        2.256
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RADIUS =     0.948                                          CYLINDER  FLAT END IMPACTING
WEIGHT =     561.8 LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG        COEFFICIENT =   0.90

 IMPACT VELOCITY EQUALS 15.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
       0.50  0.75  1.18  1.37  1.53  2.26  1.91  2.02

                   CONDITIONS AT THE END OF SECTION
                                                                       WORK DONE IN SECTION - FOOT POUNDS
  ITERATION PENETRATION    VELOCITY   SHEAR      BODY ENERGY
   SECTION      FEET        FT/SEC  STRENGTH PSF    FT-LBS        STATIC      SEDIMENT        BUOYANT      FORM DRAG
                                                                  FORCES      INERTIA         FORCES       FORCES

      1         0.0[illegible]     14.78[illegible]     3.[illegible]      1659.115        3.765      293.153         0.308       36.058
      2         0.1[illegible]     14.7[illegible]     10.[illegible]      1644.[illegible]        11.[illegible]5       -2.561         0.925       3[illegible].924
      3         0.1[illegible]     1[illegible].6[illegible]     18.[illegible]      16[illegible]3.[illegible]        1[illegible].[illegible]       -3.731         1.542       3[illegible].569
      4         0.2[illegible]     1[illegible].5[illegible]     25.[illegible]      15[illegible]5.[illegible]        26.[illegible]5       -4.882         2.159       3[illegible].083
      5         0.2[illegible]     1[illegible].3[illegible]     32.[illegible]      15[illegible]1.[illegible]        33.[illegible]6       -6.013         2.776       3[illegible].469
      6         0.30      1[illegible].20[illegible]     39.[illegible]      15[illegible]1.[illegible]        41.41[illegible]       -7.125         3.392       30.728
      7         0.3[illegible]     1[illegible].9[illegible]     46.[illegible]      14[illegible]5.[illegible]        48.[illegible]6       -8.218         4.009       29.862
      8         0.40      1[illegible].7[illegible]     54.[illegible]      14[illegible]2.410        56.[illegible]7[illegible]       -9.29[illegible]         4.626       28.874
      9         0.4[illegible]     1[illegible].49[illegible]     61.[illegible]      13[illegible]3.8[illegible]        64.[illegible]6      -10.350         5.243       27.760
     10         0.5[illegible]     1[illegible].20[illegible]     68.[illegible]      129[illegible].[illegible]7[illegible]        71.[illegible]7      -11.389         5.860       26.539
     11         0.5[illegible]     1[illegible].81[illegible]     73.[illegible]      122[illegible].[illegible]19        77.[illegible]4      -12.131         6.476       25.212
     12         0.6[illegible]     1[illegible].52[illegible]     77.4[illegible]      115[illegible].[illegible]5        80.9[illegible]      -12.579         7.093       23.818
     13         0.6[illegible]     1[illegible].152     81.[illegible]      108[illegible].[illegible]5        84.714      -13.021         7.710       22.373
     14         0.70      10.75[illegible]     84.6[illegible]0      1009.6[illegible]        88.479      -13.454         8.327       20.879
     15         0.7[illegible]     1[illegible].327     88.2[illegible]      93[illegible].1[illegible]        92.[illegible]5      -13.880         8.944       19.337
     16         0.80      [illegible].86[illegible]     91.8[illegible]      85[illegible].204        96.010      -14.300         9.560       17.746
     17         0.8[illegible]     [illegible].37[illegible]     95.4[illegible]      76[illegible].9[illegible]2        99.7[illegible]5      -14.712        10.177       16.109
     18         0.9[illegible]     [illegible].83[illegible]     99.0[illegible]      68[illegible].3[illegible]7       103.5[illegible]0      -15.117        10.794       14.424
     19         0.9[illegible]     [illegible].24[illegible]    10[illegible].6[illegible]      59[illegible].579       107.[illegible]05      -15.515        11.411       12.694
     20         1.00      7.59[illegible]    1[illegible].2[illegible]      50[illegible].5[illegible]       111.[illegible]70      -15.906        12.028       10.919
     21         1.05      6.85[illegible]    11[illegible].[illegible]      410.2[illegible]4       116.190      -16.493        12.644        9.086
     22         1.10      5.983    117.[illegible]      312.470       122.665      -17.271        13.261        7.173
     23         1.15      4.909    123.[illegible]      210.406       129.142      -18.034        13.878        5.165
     24         1.20      3.453    129.872      104.114       135.618      -18.781        14.495        3.048
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                                                  CYLINDER  FLAT END IMPACTING
RADIUS =    0.948
WEIGHT =    561.8 LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG      COEFFICIENT =  0.90


 IMPACT VELOCITY EQUALS 20.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
      0.73  1.00  0.99  1.08  1.52  1.91  2.39  2.95

              CONDITIONS AT THE END OF SECTION                     WORK DONE IN SECTION - FOOT POUNDS

     ITERATION PENETRATION    VELOCITY   SHEAR      BODY ENERGY     STATIC     SEDIMENT      BUOYANT    FORM DRAG
      SECTION     FEET         FT/SEC  STRENGTH PSF    FT-LBS       FORCES     INERTIA       FORCES     FORCES

        1          0.05       19.327   [illegible]  [illegible]      5.497     518.122       0.308      63.926
        2          0.10       18.701   [illegible]  [illegible]     16.491      -7.115       0.925      58.044
        3          0.15   [illegible]     26.380    [illegible]     27.485      -8.724       1.542      57.151
        4          0.20   [illegible]  [illegible]  [illegible]     38.479     -10.307       2.159      56.078
        5          0.25   [illegible]  [illegible]  [illegible]     49.473     -11.861       2.776      54.827
        6          0.30   [illegible]  [illegible]  [illegible]     60.467     -13.392       3.392      53.403
        7          0.35       17.114   [illegible]  [illegible]     71.461     -14.895       4.009      51.807
        8          0.40       16.803   [illegible]  [illegible]     82.455     -16.374       4.626      50.043
        9          0.45   [illegible]  [illegible]  [illegible]     93.449     -17.827       5.243      48.113
       10          0.50       16.070   [illegible]  [illegible]    104.443     -19.257       5.860      46.021
       11          0.55   [illegible]  [illegible]  [illegible]    111.974     -20.166       6.476      43.768
       12          0.60   [illegible]  [illegible]  [illegible]    116.040     -20.505       7.093      41.504
       13          0.65   [illegible]  [illegible]  [illegible]    120.106     -20.857       7.710      39.171
       14          0.70       14.305   [illegible]  [illegible]    124.172     -21.204       8.327      36.798
       15          0.75   [illegible]  [illegible]  [illegible]    128.238     -21.545       8.944      34.386
       16          0.80   [illegible]  [illegible]     1540.717    132.305     -21.880       9.560      31.935
       17          0.85       12.731   [illegible]  [illegible]    136.371     -22.210      10.177      29.447
       18          0.90       12.144   [illegible]  [illegible]    140.439     -22.534      10.794      26.922
       19          0.95   [illegible]  [illegible]  [illegible]    144.504     -22.853      11.411      24.360
       20          1.00   [illegible]  [illegible]     1027.041    148.570     -23.166      12.028      21.763
       21          1.05       10.131   [illegible]  [illegible]    150.528     -23.160      12.644      19.147
       22          1.10        9.371   [illegible]      765.706    150.377     -22.840      13.261      16.550
       23          1.15   [illegible]  [illegible]  [illegible]    150.227     -22.525      13.878      13.938
       24          1.20        7.669   [illegible]  [illegible]    150.076     -22.215      14.495      11.459
       25          1.25        6.672   [illegible]  [illegible]    149.926     -21.910      15.112       8.962
       26          1.30   [illegible]  [illegible]      267.126    149.775     -21.609      15.728       6.493
       27          1.35   [illegible]  [illegible]  [illegible]    149.624     -21.311      16.345       4.040
       28          1.40        1.782   [illegible]       27.726    149.474     -21.001      16.962       1.512
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RADIUS =     0.948                                   CYLINDER  FLAT END IMPACTING
WEIGHT =     561.8 LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG      COEFFICIENT =  0.90

 IMPACT VELOCITY EQUALS  5.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
      0.21  0.31  0.60  1.44  1.44  2.44  2.55  2.44

               CONDITIONS AT THE END OF SECTION
                                                          WORK DONE IN SECTION - FOOT POUNDS
ITERATION PENETRATION    VELOCITY   SHEAR    BODY ENERGY
 SECTION      FEET        FT/SEC  STRENGTH PSF  FT-LBS      STATIC     SEDIMENT      BUOYANT     FORM DRAG
                                                            FORCES     INERTIA       FORCES      FORCES

    1         0.05        4.836      1.512    204.170       1.581      36.075        0.308        4.209
    2         0.10        5.016      4.536    219.634       4.744       2.732        0.925        4.221
    3         0.15        5.151      7.560    231.652       7.907       2.124        1.542        4.496
    4         0.20        5.246     10.584    240.294      11.069       1.525        2.159        4.702
    5         0.25        5.304     13.608    245.595      14.232       0.937        2.776        4.842
    6         0.30        5.326     16.632    247.611      17.395       0.358        3.392        4.915
    7         0.35        5.313     19.656    246.419      20.557      -0.211        4.009        4.923
    8         0.40        5.266     22.680    242.061      23.720      -0.770        4.626        4.868
    9         0.45        5.184     25.704    234.592      26.883      -1.320        5.243        4.750
   10         0.50        5.066     28.728    224.063      30.045      -1.850        5.860        4.571
   11         0.55        4.919     30.960    211.225      32.380      -2.265        6.476        4.337
   12         0.60        4.748     32.400    196.816      33.886      -2.546        7.093        4.066
   13         0.65        4.551     33.840    180.855      35.392      -2.820        7.710        3.763
   14         0.70        4.326     35.280    163.373      36.898      -3.082        8.327        3.429
   15         0.75        4.067     36.720    144.403      38.404      -3.352        8.944        3.065
   16         0.80        3.768     38.160    123.963      39.910      -3.612        9.560        2.671
   17         0.85        3.419     39.600    102.076      41.416      -3.867       10.177        2.248
   18         0.90        3.004     41.040     78.773      42.922      -4.118       10.794        1.796
   19         0.95        2.489     42.480     54.070      44.428      -4.364       11.411        1.313
   20         1.00        1.791     43.920     28.003      45.934      -4.606       12.028        0.798
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                                                  CYLINDER  FLAT END IMPACTING

RADIUS =    0.948
WEIGHT =    561.8 LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG      COEFFICIENT =  0.90


 IMPACT VELOCITY EQUALS 10.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

     0.21  0.57  1.46  2.11  2.05  2.07  2.09  2.30


             CONDITIONS AT THE END OF SECTION                     WORK DONE IN SECTION - FOOT POUNDS

   ITERATION PENETRATION    VELOCITY   SHEAR     BODY ENERGY      STATIC     SEDIMENT      BUOYANT    FORM DRAG
    SECTION      FEET        FT/SEC  STRENGTH PSF   FT-LBS        FORCES     INERTIA       FORCES     FORCES

       1          0.05        9.272        1.512     750.462       1.581     132.601        0.308      16.161
       2          0.10        9.310  [illegible]     756.749       4.744       1.111        0.925      15.020
       3          0.15        9.326  [illegible]     759.746       7.907       0.529        1.542      15.112
       4          0.20        9.337  [illegible]     759.507      11.069      -0.042        2.159      15.140
       5          0.25  [illegible]  [illegible]     756.037      14.232      -0.604        2.776      15.104
       6          0.30  [illegible]  [illegible]     749.519      17.395      -1.157        3.392      15.005
       7          0.35  [illegible]  [illegible]     739.910      20.557      -1.700        4.009      14.843
       8          0.40  [illegible]  [illegible]     727.270      23.720      -2.234        4.626      14.622
       9          0.45  [illegible]       25.704     711.651      26.883      -2.760        5.243      14.340
      10          0.50        8.910  [illegible]     693.109      30.045      -3.276        5.860      13.999
      11          0.55        8.745       32.842     670.743      34.339      -3.952        6.476      13.592
      12          0.60        8.566  [illegible]     643.663      39.759      -4.785        7.093      13.098
      13          0.65        8.372  [illegible]     611.960      45.181      -5.605        7.710      12.512
      14          0.70        8.120  [illegible]     575.682      50.603      -6.408        8.327      11.834
      15          0.75        7.828       53.549     534.935      56.024      -7.200        8.944      11.066
      16          0.80  [illegible]       58.752     489.784      61.446      -7.978        9.560      10.209
      17          0.85        7.102       63.925     440.304      66.868      -8.743       10.177       9.264
      18          0.90        6.694       68.120     386.569      72.290      -9.495       10.794       8.234
      19          0.95        6.135       74.304     328.648      77.711     -10.234       11.411       7.118
      20          1.00        5.526  [illegible]     266.616      83.133     -10.961       12.028       5.919
      21          1.05        4.752       88.468     197.182      92.545     -12.268       12.644       4.599
      22          1.10        3.663      101.394     117.121     105.349     -14.146       13.261       3.084
      23          1.15        1.748      114.120      26.679     119.353     -15.980       13.878       1.279
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                                                CYLINDER  FLAT END IMPACTING
RADIUS =     0.948
WEIGHT =     561.8 LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG      COEFFICIENT =  0.90

 IMPACT VELOCITY EQUALS 15.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
       0.36  0.45  0.40  1.22  1.39  1.74  2.35  2.90

              CONDITIONS AT THE END OF SECTION
                                                                WORK DONE IN SECTION - FOOT POUNDS
     ITERATION PENETRATION    VELOCITY   SHEAR      BODY ENERGY
      SECTION     FEET         FT/SEC  STRENGTH PSF    FT-LBS      STATIC     SEDIMENT     BUOYANT     FORM DRAG
                                                                   FORCES     INERTIA      FORCES      FORCES

        1         0.05       13.789      2.592     1660.002       2.711     293.310       0.309      36.068
        2         0.10       13.740      7.776     1648.157       8.133      -2.023       0.925      32.968
        3         0.15       13.670     12.960     1631.422      13.554      -2.957       1.542      32.683
        4         0.20       13.579     18.144     1609.879      18.976      -3.807       2.159      32.302
        5         0.25       13.468     23.328     1583.609      24.398      -4.642       2.776      31.825
        6         0.30       13.335     28.512     1552.692      29.819      -5.463       3.392      31.255
        7         0.35       13.183     33.696     1517.205      35.241      -6.270       4.009      30.594
        8         0.40       13.008     38.880     1477.226      40.663      -7.064       4.626      29.841
        9         0.45       12.811     44.064     1432.829      46.085      -7.844       5.243      29.000
       10         0.50       12.591     49.248     1384.091      51.506      -8.612       5.860      28.072
       11         0.55       12.356     52.488     1332.795      54.895      -9.033       6.476      27.075
       12         0.60       12.112     53.784     1280.699      56.250      -9.205       7.093      26.044
       13         0.65       11.859     55.080     1227.816      57.606      -9.344       7.710      24.998
       14         0.70       11.597     56.376     1174.159      58.961      -9.431       8.327      23.936
       15         0.75       11.325     57.672     1119.742      60.317      -9.615       8.944      22.859
       16         0.80       11.043     58.968     1064.577      61.672      -9.747       9.560      21.767
       17         0.85       10.749     60.264     1008.677      63.027      -9.877      10.177      20.660
       18         0.90       10.443     61.560      952.054      64.383     -10.005      10.794      19.538
       19         0.95       10.123     62.856      894.720      65.738     -10.130      11.411      18.402
       20         1.00        9.790     64.152      836.688      67.094     -10.254      12.028      17.252
       21         1.05        9.445     64.440      778.356      67.395     -10.218      12.644      16.097
       22         1.10        9.095     63.720      722.112      66.642     -10.026      13.261      14.955
       23         1.15        8.737     63.000      666.435      65.889      -9.838      13.878      13.834
       24         1.20        8.371     62.280      611.308      65.136      -9.652      14.495      12.735
       25         1.25        7.996     61.560      558.214      64.383      -9.470      15.112      11.656
       26         1.30        7.610     60.840      505.035      63.630      -9.290      15.728      10.598
       27         1.35        7.212     60.120      454.054      62.877      -9.114      16.345       9.559
       28         1.40        6.798     59.400      403.455      62.124      -8.940      16.962       8.540
       29         1.45        6.366     58.680      353.821      61.371      -8.770      17.579       7.541
       30         1.50        5.912     57.960      305.137      60.618      -8.602      18.196       6.560
       31         1.55        5.371     63.504      251.867      65.416      -8.412      18.812       5.540
       32         1.60        4.648     73.312      188.574      78.765     -11.193      19.429       4.369
       33         1.65        3.636     87.120      115.435      91.115     -12.923      20.046       2.989
       34         1.70        1.934     98.928       32.665     103.464     -14.625      20.663       1.355
```

```
RADIUS =     0.948
WEIGHT =     561.8 LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG        COEFFICIENT =   0.90


 IMPACT VELOCITY EQUALS 20.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
       0.70   1.04   1.39   2.26   2.32   2.70   2.79   2.76


                 CONDITIONS AT THE END OF SECTION
                                                                    WORK DONE IN SECTION - FOOT POUNDS
     ITERATION PENETRATION     VELOCITY    SHEAR       BODY ENERGY
      SECTION      FEET         FT/SEC   STRENGTH PSF    FT-LBS         STATIC       SEDIMENT      BUOYANT      FORM DRAG
                                                                        FORCES       INERTIA       FORCES       FORCES

         1          0.05        18.328      5.[illegible]     2932.529        5.271      518.156        0.308        63.928
         2          0.10        18.203     15.[illegible]     2892.832       15.813       -7.014        0.925        58.054
         3          0.15        18.050     25.[illegible]     2844.398       26.356       -8.558        1.542        57.175
         4          0.20        17.868     35.[illegible]     2787.373       36.898      -10.076        2.159        56.124
         5          0.25        17.657     45.[illegible]     2721.904       47.440      -11.568        2.776        54.904
         6          0.30        17.416     55.[illegible]     2648.129       57.982      -13.035        3.392        53.516
         7          0.35        17.145     65.[illegible]     2566.191       68.524      -14.478        4.009        51.964
         8          0.40        16.842     75.[illegible]     2476.227       79.067      -15.896        4.626        50.253
         9          0.45        16.505     85.[illegible]     2378.369       89.609      -17.291        5.243        48.378
        10          0.50        16.135     95.[illegible]     2272.754      100.151      -18.661        5.860        46.349
        11          0.55        15.736    103.[illegible]     2161.795      107.983      -19.605        6.476        44.190
        12          0.60        15.316    108.[illegible]     2047.867      113.103      -20.130        7.093        41.949
        13          0.65        14.872    113.[illegible]     1931.017      118.224      -20.646        7.710        39.648
        14          0.70        14.404    117.[illegible]     1811.296      123.344      -21.154        8.327        37.290
        15          0.75        13.908    122.[illegible]     1688.753      128.465      -21.652        8.944        34.874
        16          0.80        13.382    127.[illegible]     1563.434      133.585      -22.143        9.560        32.403
        17          0.85        12.822    132.[illegible]     1435.387      138.706      -22.625       10.177        29.877
        18          0.90        12.225    137.[illegible]     1304.656      143.826      -23.099       10.794        27.296
        19          0.95        11.583    142.[illegible]     1171.289      148.947      -23.565       11.411        24.662
        20          1.00        10.890    147.[illegible]     1035.329      154.067      -24.023       12.028        21.977
        21          1.05        10.135    152.[illegible]      896.758      159.263      -24.484       12.644        19.235
        22          1.10         9.303    157.[illegible]      755.556      164.534      -24.949       13.261        16.442
        23          1.15         8.371    162.[illegible]      611.771      169.805      -25.406       13.878        13.595
        24          1.20         7.202    167.400      465.449      175.076      -25.854       14.495        10.692
        25          1.25         6.022    172.[illegible]      316.640      180.347      -26.293       15.112         7.730
        26          1.30         4.353    177.400      165.411      185.619      -26.721       15.728         4.690
        27          1.35         1.174    182.[illegible]       12.023      190.890      -27.103       16.345         1.343
```

APPENDIX F: COMPUTATION OF THE PENETRATION OF A CUBE

```
C DYNAMIC PENETRATION OF AN OBJECT INTO THE OCEAN BOTTOM
C PROGRAM TO CALCULATE SECTION PROPERTIES OF A CUBE
C
C UNITS FEET/POUNDS/SLUGS/SECONDS/
C
C DX       INCREMENT SIZE
C
C BWD      BULK WET DENSITY OF SEDIMENT
C
C BMASS    OBJECT MASS
C
C AMASS()  ADDED MASS PLUS MASS OF DISPLACED SEDIMENT AT SECTION ( )
C
C DMASS( )CHANGE IN AMASS OVER SECTION INDICATED BY SUBSCRIPT
C
C AREA( )  PROJECTED AREA FOR SECTION ( )
C
C CNC      BEARING CAPACITY COEFFICIENT
C
C VOL( )   VOLUME OF SECTION ( )
C
C CFOOT    BEARING CAPACITY CONSTANT DEPENDS ON SHAPE OF AREA
C
C XXX      DEPTH OF PENETRATION
C
C SVOL( )  SUM OF VOLUMES TO SECTION INDICATED
C
C V( )     VELOCITY OF OBJECT AT SECTION ( )
C
C WS( )    WORK DONE BY SEDIMENT IN SECTION ( )
C
C WT       WEIGHT OF OBJECT
C
C G        ACCELERATION OF GRAVITY
C
C SPS      SHEAR STRENGTH OF SEDIMENT
C
C RAD      RADIUS OF AN EQUIVALENT CROSS SECTIONAL AREA
C
C DIM      LENGTH OF ONE SIDE
C
C WDRAG    WORK DONE BY DRAG FORCES
C
C WB( )    WORK DONE BY BUOYANCY WHEN SUBMERGING TO SECTION ( )
```

```
C
C WBSUB( )WORK DONE BY SUBMERGED SECTION ( )
C
C US( )    WORK TO SUBMERGE SECTION ( )
C
C SUMSUB()WORK DONE BY SUBMERGED SECTIONS TO SECTION( )
C
C E( )     KINETIC ENERGY OF BODY AT SECTION( )
C
C
      DIMENSION AREA(100),VOL(100),AMASS(100),DMASS(100),SVOL(100),WS(10
     20),WB(100),WBSUB(50),US(50),SUMSUB(50),E(100),V(100)
C     RESET DIMENSIONS FOR LARGE OBJECTS
      DATA PI/3.141593/,G/32.1725/,AREA/100*0.0/,VOL/100*0.0/,AMASS/100*
     20.0/,DMASS/100*0.0/,SVOL/100*0.0/,WS/100*0.0/,WB/100*0.0/,WBSUB/50
     3*0.0/,US/50*0.0/,SUMSUB/50*0.0/,E/100*0.0/,V/100*0.0/
C
C
C
C     INPUT DATA ON OBJECT
C     OBJECT CUBE
      DIM=2.0
C     THE RADIUS OF AN EQUIVALENT CIRCULAR AREA IS.
      RAD=SQRT(DIM**2/PI)
      WT=702.75
      BWD=37.402/G
      CFOOT=1.3
      CNC=5.7
C     COHESION OR SHEAR STRENGTH IN PSI EQUALS .3 FOR PROGRAM CHECKOUT
      COH=43.2
C
C     FOR A CUBE USE A COEFFICIENT OF DRAG EQUAL TO 1.1
      CD=1.1
C
C
C     SET INCREMENT
      DX=.05
C
C
C
C
C     CALCULATE THE SECTION PROPERTIES,AVERAGE PROJECTED AREA,VOLUME
C     FIND AREA AT MIDPOINT OF EACH SECTION
C     Y=DISTANCE ABOVE BOTTOM OF CUBE
      Y=DX/2.
      Z=DIM/DX
      N=Z+1
      AREA(1)=DIM**2
C
```

```
C     FOR THIS ANALYSIS THE AREA IS
C     CONSTANT FOR THE REMAINING PENETRATION THEREFORE SET SUCCEEDING
C     AREAS AS FOLLOWS
      DO 200 I=1.100
      AREA(I)=AREA(1)
C     PRINT, AREA(I)
  200 CONTINUE
C
C
C
C     COMPUTE THE VOLUME OF EACH SECTION
C     VOLUME EQUALS AVERAGE AREA TIMES SECTION HEIGHT
C
      DO 300 I=1,100
      VOL(I)=AREA(I)*DX
  300 CONTINUE
C
C     CHECK VOLUME CALCULATIONS
      HAFVOL=DIM**3
      CVOL=VOL(1)
      DO 350 I=2,N
      CVOL=CVOL+VOL(I)
  350 CONTINUE
C
      ERROR=CVOL-HAFVOL
C     PRINT,CVOL,HAFVOL,ERROR
C
C
C
C     CALCULATE ADDED MASS, DISPLACED MASS AND CHANGE IN ADDED MASS PLUS
C     DISPLACED MASS FROM SECTION TO SECTION.
C     APPROXIMATE BY USING ONE HALF OF A CIRCULAR DISK WITH AN
C     EQUIVALENT AREA
C     AMASS BECOMES CONSTANT WHEN THE MAXIMUM AREA HAS BEEN REACHED.
C
      SUMVOL=0.0
      K=N+1
      DO 400 I=2,K
C     SEE PAGE 421 OF SAUNDERS FOR FORMULAS BELOW
      AMASS(I-1)=BWD*(4./3.)*RAD**3
C
C     SINCE SEPARATION OCCURS AT IMPACT AMASS REMAINS CONSTANT AND THERE
C     IS NO CONTRIBUTION FROM THE DISPLACED MASS
C
  400 CONTINUE
C
      DO 450 I=N,100
      AMASS(I)=AMASS(N)
```

```
C     PRINT,AMASS(I)
  450 CONTINUE
C
C     COMPUTE CHANGE IN AMASS FROM SECTION TO SECTION
      DMASS(1)=0.0
      DO 500 I=2,N
      DMASS(I)=AMASS(I)-AMASS(I-1)
C     PRINT,DMASS(I)
  500 CONTINUE
C
C     SUM DMASS, IT SHOULD BE CLOSE TO AMASS(N)
C
      CDMASS=DMASS(1)
      DO 550 I=2,N
      CDMASS=CDMASS+DMASS(I)
  550 CONTINUE
C     PRINT,CDMASS,AMASS(N)
C
C
C
C     CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C     PER SECTION IF THE SHEAR STRENGTH IS CONSTANT FOR PROGRAM CHECK
C     ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X COHESIONX DX
      CT=CFOOT*CNC
      DO 600 I=1,100
      WS(I)=CT*COH*AREA(I)*DX
C     PRINT,WS(I)
  600 CONTINUE
C
C
C
C     CALCULATE WORK DONE BY BUOYANCY
C
C

      GAMMA=PWD*G
      WB(1)=(GAMMA*AREA(1)*DX**2)/2.
      SUMSUB(1)=2.0*WB(1)
      DO 700 I=2,N
C
C     WORK TO SUBMERGE SECTION
      US(I)=(GAMMA*AREA(I)*DY**2)/2.
C
C     WORK TO CONTINUE SECTION AFTER SUBMERGING
      WBSUB(I)=2.0*US(I)
C
C     TOTAL WORK OF THE SUBMERGED SECTIONS
      SUMSUB(I)=SUMSUB(I-1)+WBSUB(I)
C
```

```
C     TOTAL WORK DONE SUBMERGING SECTION PLUS THOSE ALREADY SUBMERGED
      WB(I)=US(I)+SUMSUB(I-1)
  700 CONTINUE
C
C     AFTER ALL SECTIONS ARE SUBMERGED WORK BECOMES CONSTANT EQUAL TO
C     SUMSUB(N) PLUS WBSUB(N) FOR EACH FURTHUR INCREMENT
C     THIS ASSUMES A CAVITY IS FORMED AFTER THE OBJECT PENETRATES PAST
C     ITS MAXIMUM DIMENSION
C
      DO 760 I=N,100
      WB(I)=SUMSUB(N)+(I-(N-1))*WBSUB(N)
C     PRINT,WB(I)
  760 CONTINUE
C
C     CHECK WORK TO SUBMERGE
C
      CWB=WB(1)
      DO 800 I=2,N
      CWB=CWB+WB(I)
  800 CONTINUE
C     PRINT,CWB
C
C     ACTUAL WORK BY INTEGRATION IS
C
      X=N*DX
      AWB=(GAMMA*DIM**2*X**2/2.)
C     PRINT,AWB,X
C
C
C
C
C     PROGRAM TO COMPUTE PENETRATION DEPTH FOLLOWS
C
      BE ABLE TO DO NNN DIFFERENT VELOCITIES AND SHEAR STRENGTHS
      READ(5,2050) NNN
      WRITE(6,2060)NNN
C
      DO 1000 J=1,NNN
      WRITE(6,2200) DIM,WT,BWD,CD
C
C     READ IN THE VELOCITIES AND SHEAR STRENGTHS
      READ(5,2100) VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40
      WRITE(6,2300)VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40
      WRITE(6,2500)
C
C
C     CALCULATE ORIGINAL ENERGY OF BODY AT INTERFACE
      BMASS=WT/G
```

```
      E(1)=BMASS*VO**2/2.
C
C     CALCULATE POTENTIAL ENERGY FOR EACH INCREMENT
      EP=WT*DX
C
C
C     COMPUTE SLOPE OF SHEAR STRENGTH VARIATIONS
C
      SLOPE1=SS05/.5
      BINT1=0.0
C
      SLOPE2=(SS10-SS05)/.5
      BINT2=-SLOPE2*.5+SS05
C
      SLOPE3=(SS105-SS10)/.5
      BINT3=-SLOPE3*1.+SS10
C
      SLOPE4=(SS20-SS105)/.5
      BINT4=-SLOPE4*1.5+SS105
C
      SLOPE5=(SS205-SS20)/.5
      BINT5=-SLOPE5*2.0+SS20
C
      SLOPE6=(SS30-SS205)/.5
      BINT6=-SLOPE6*2.5+SS205
C
      SLOPE7=(SS305-SS30)/.5
      BINT7=-SLOPE7*3.+SS30
C
      SLOPE8=(SS40-SS305)/.5
      BINT8=-SLOPE8*3.5+SS305
C
C
C     VELOCITY OF SEDIMENT AT INTERFACE IS ALWAYS 0 AT INSTANT OF IMPACT
      V(1)=0.0
      DO 2000 I=1,100
C     SECTION TO COMPUTE SHEAR STRENGTH
C     NCTE THAT THE SHEAR STRENGTH IS COMPUTED IN INCHES THEN CONVERTED
C     TO POUNDS PER SQUARE FOOT FOR THE CALCULATION
C
C     FOR THE CUBE TAKE THE DEPTH FOR SHEAR STRENGTH TO BE THE PENETRA
C     TION DEPTH
      DEPTH=I*DX-Y
C
C     CONVERT THE DEPTH TO INCHES FOR EASY COMPARISON WITH  DATA
      DEPTHI=DEPTH*12.
C
C     SELECT PROPER DEPTH
```

```
      IF(DEPTH.LE..5) GO TO 1
      IF((DEPTH.LE.1.0).AND.(DEPTH.GT.0.5)) GO TO 2
      IF((DEPTH.LE.1.5).AND.(DEPTH.GT.1.0)) GO TO 3
      IF((DEPTH.LE.2.0).AND.(DEPTH.GT.1.5)) GO TO 4
      IF((DEPTH.LE.2.5).AND.(DEPTH.GT.2.0)) GO TO 5
      IF((DEPTH.LE.3.0).AND.(DEPTH.GT.2.5)) GO TO 6
      IF((DEPTH.LE.3.5).AND.(DEPTH.GT.3.0)) GO TO 7
      IF((DEPTH.LE.4.0).AND.(DEPTH.GT.3.5)) GO TO 8
C
C     FOR DEPTHS LARGER THAN LAST SHEAR STRENGTH TAKE THE ARITHMETIC
C     AVERAGE OF THE LAST THREE AND CALL IT CONSTANT
C
      IF(DEPTH.GT.4.0) GO TO 9
C
C     FORMULAS FOR SHEAR STRENGTH FOLLOW
C     LINEAR VARIATION BETWEEN MEASURED POINTS IS ASSUMED
C
    1 SSS=SLOPE1*DEPTH
      GO TO 10
    2 SSS=SLOPE2*DEPTH+BINT2
      GO TO 10
    3 SSS=SLOPE3*DEPTH+BINT3
      GO TO 10
    4 SSS=SLOPE4*DEPTH+BINT4
      GO TO 10
    5 SSS=SLOPE5*DEPTH+BINT5
      GO TO 10
    6 SSS=SLOPE6*DEPTH+BINT6
      GO TO 10
    7 SSS=SLOPE7*DEPTH+BINT7
      GO TO 10
    8 SSS=SLOPE8*DEPTH+BINT8
      GO TO 10
C
    9 SSS=(SS30+SS305+SS40)/3.
C
C     SPS IS THE SHEAR STRENGTH IN POUNDS PER SQUARE FOOT
   10 SPS=SSS*144.
C     CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C     ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X SPS X DX
      CT=CFOOT*CNC
      WS(I)=CT*SPS*AREA(I)*DX
      AMASS1=(AMASS(I)*V(I)**2/2.)
      VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I))/(BMASS+DMASS(I)+AMASS(I))
      IF (VELOSQ.LE.0.0)GO TO 1000
      V(I+1)=SQRT(VELOSQ)
C
C
```

```
C        SECTION TO COMPUTE THE WORK DONE BY DRAG
C        APPROXIMATE AVERAGE VELOCITY OVER A SECTION BY NEGLECTING THE DRAG
C        FIRST TIME OVER THE SECTION, AS DONE ABOVE
         VAVG=(V(I)+V(I+1))/2.
         IF(I.EQ.1) VAVG=(VO+V(I+1))/2.
         WDRAG=.5*BWD*CD*AREA(I)*DX*VAVG**2
C
         VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I)-WDRAG)/(BMASS+DMASS(I)+AMAS
        2S(I))
         IF (VELOSQ.LE.0.0)GO TO 1000
         V(I+1)=SQRT(VELOSQ)
C
C        CALCULATE E AT NEXT SECTION
         E(I+1)=BMASS*V(I+1)**2/2.
C
C        CALCULATE ENERGY DISSIPATED BY ADDED MASS EFFECTS, EAM
         EAM=.5*(AMASS(I)*V(I+1)**2-2.0*AMASS1+DMASS(I)*V(I+1)**2)
C
C        COMPUTE PENETRATION DEPTH
         XXX=I*DX
C
C        PRINT THE SECTION, DEPTH OF PENETRATION, VELOCITY AT THE END OF
C        SECTION, SHEAR STRENGTH IN SECTION, BODY ENERGY AT END OF SECTION,
C        WORK DONE BY   SEDIMENT, ADDED MASS PLUS DISPLACED MASS, BUOYANCY,
C        AND DRAG
C
         WRITE(6,2600) I,XXX,V(I+1),SPS,E(I+1),WS(I),EAM,WB(I),WDRAG
 2000    CONTINUE
 1000    CONTINUE
 2050    FORMAT(I5)
 2060    FORMAT(' ',I3)
 2100    FORMAT(F5.1,8F5.2)
 2200    FORMAT('1',60X,'CUBE'//9X,'SIDE    = ',F7.3/9X,'WEIGHT = ',F7.1,'
        2LBS'/9X,'BULK WET DENSITY = ',F5.2,'SLUGS PER CUBIC FOOT'/9X,'DRAG
        3 COEFFICIENT = ',F5.2///)
 2300    FORMAT(' ',10X,'IMPACT VELOCITY EQUALS',F5.1///10X,'SEDIMENT SHEAR
        2 STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE'//15X,8F6.2//)
 2500    FORMAT('0',28X,'CONDITIONS AT THE END OF SECTION',19X,'WORK DONE I
        2N SECTION - FOOT POUNDS'///16X,'ITERATION',1X,'PENETRATION',4X,'VE
        3LOCITY',3X,'SHEAR',5X,'BODY ENERGY',6X,'STATIC',4X,'SEDIMENT',5X,'
        4BUOYANT',3X,'FORM DRAG'/17X,'SECTION',6X,'FEET',8X,'FT/SEC',2X,'ST
        5RENGTH PSF',4X,'FT-LBS',7X,'FORCES',4X,'INERTIA',6X,'FORCES',4X,'F
        6ORCES'//)
 2600    FORMAT(' ',16X,I3,3X,F12.2,7F12.3)
         STOP
         END
```

```
                                        CUBE
SIDE   =    2.000
WEIGHT =    702.8  LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  1.10

 IMPACT VELOCITY EQUALS  0.0

 SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
       0.48  0.85  1.30  1.70  2.00  1.75  1.40  1.20

                  CONDITIONS AT THE END OF SECTION
                                                                     WORK DONE IN SECTION - FOOT POUNDS
     ITERATION PENETRATION      VELOCITY   SHEAR      BODY ENERGY
      SECTION     FEET           FT/SEC  STRENGTH- PSF   FT-LBS       STATIC      SEDIMENT      BUOYANT    FORM DRAG
                                                                      FORCES      INERTIA       FORCES     FORCES
         1         0.05          1.475       3.456      23.756         5.122       5.660        0.437       0.163
         2         0.10          1.84?      10.??8      37.985        15.365       3.390        1.311       0.542
         3         0.15          1.9?4      17.?10      43.012        25.609       1.198        2.185       1.116
         4         0.20          1.8?1      24.?62      39.047        35.853      -0.945        3.059       1.135
         5         0.25          1.55?      31.?04      26.?97        46.096      -3.038        3.933       0.836
         6         0.30          0.67?      38.016       4.987        56.340      -5.077        4.807       0.377

 IMPACT VELOCITY EQUALS  5.0

 SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
       0.80  1.04  1.13  0.87  1.23  1.?3  1.54  1.5?

                  CONDITIONS AT THE END OF SECTION
                                                                     WORK DONE IN SECTION - FOOT POUNDS
     ITERATION PENETRATION      VELOCITY   SHEAR      BODY ENERGY
      SECTION     FEET           FT/SEC  STRENGTH PSF   FT-LBS        STATIC      SEDIMENT      BUOYANT    FORM DRAG
                                                                      FORCES      INERTIA       FORCES     FORCES
         1         0.05          4.649       5.760     235.954         8.536      56.215        0.437       7.035
         2         0.10          4.661      17.280     237.303        25.609       0.321        1.311       6.547
         3         0.15          4.532      28.800     224.29?        42.682      -3.101        2.185       6.385
         4         0.20          4.250      40.320     197.2??        59.754      -6.446        3.059       5.?27
         5         0.25          3.7??      51.840     156.4??        76.827      -9.717        3.933       4.980
         6         0.30          3.0??      63.360     102.24?        93.899     -12.913        4.807       3.543
         7         0.35          1.799      74.880      34.?75       110.972     -16.027        5.681       1.783
```

```
                                   CUBE
SIDE   =    2.000
WEIGHT =    702.8   LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  1.10


 IMPACT VELOCITY EQUALS 10.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

      0.50  0.71  1.01  2.00  2.05  2.10  2.33  2.10


           CONDITIONS AT THE END OF SECTION                      WORK DONE IN SECTION - FOOT POUNDS

   ITERATION PENETRATION     VELOCITY   SHEAR     BODY ENERGY       STATIC     SEDIMENT       BUOYANT    FORM DRAG
    SECTION      FEET         FT/SEC  STRENGTH PSF    FT-LBS         FORCES     INERTIA        FORCES     FORCES

       1          0.05         8.995      3.600      883.711        5.335     210.540         0.437      27.273
       2          0.10         8.968     10.800      878.416       16.006      -1.261         1.311      24.376
       3          0.15         8.894     18.000      864.018       26.676      -3.420         2.185      24.104
       4          0.20         8.774     25.200      840.718       37.346      -5.551         3.059      23.593
       5          0.25         8.605     32.400      808.712       48.017      -7.625         3.933      22.817
       6          0.30         8.387     39.600      768.195       58.687      -9.653         4.807      21.813
       7          0.35         8.116     46.800      719.343       69.357     -11.626         5.681      20.576
       8          0.40         7.788     54.000      662.372       80.028     -13.575         6.555      19.110
       9          0.45         7.397     61.200      597.432       90.698     -15.472         7.429      17.421
      10          0.50         6.931     68.400      524.730      101.369     -17.325         8.303      15.512
      11          0.55         6.395     73.512      446.860      108.945     -18.550         9.177      13.424
      12          0.60         5.792     76.536      366.458      113.426     -19.153        10.051      11.229
      13          0.65         5.095     79.560      283.532      117.908     -19.752        10.925       8.951
      14          0.70         4.260     82.584      198.183      122.399     -20.332        11.799       6.618
      15          0.75         3.181     85.608      110.481      126.871     -20.895        12.673       4.190
      16          0.80         1.372     88.632       20.573      131.353     -21.422        13.547       1.577
```

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```
                                                    CUBE
  SIDE   =    2.000
  WEIGHT =    702.8  LBS
  BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
  DRAG COEFFICIENT =  1.10


    IMPACT VELOCITY EQUALS 15.0

   SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

          0.61  0.72  1.40  1.90  1.88  1.74  1.55  1.60


                    CONDITIONS AT THE END OF SECTION                        WORK DONE IN SECTION - FOOT POUNDS

        ITERATION PENETRATION     VELOCITY   SHEAR      BODY ENERGY       STATIC     SEDIMENT       BUOYANT    FORM DRAG
         SECTION      FEET         FT/SEC  STRENGTH PSF    FT-LBS         FORCES     INERTIA        FORCES     FORCES

             1        0.05        13.390      4.392     1958.113         6.509    466.510         0.437      60.925
             2        0.10        13.281     13.176     1926.263        19.527     -7.588         1.311      53.735
             3        0.15        13.134     21.960     1884.022        32.545    -10.064         2.185      52.710
             4        0.20        12.950     30.744     1831.420        45.563    -12.484         3.059      51.401
             5        0.25        12.728     39.528     1769.281        58.580    -14.852         3.933      49.813
             6        0.30        12.466     48.312     1697.225        71.598    -17.167         4.807      47.963
             7        0.35        12.163     57.096     1615.667        84.616    -19.430         5.681      45.827
             8        0.40        11.816     65.880     1524.918        97.634    -21.644         6.555      43.441
             9        0.45        11.421     74.664     1424.683       110.652    -23.809         7.429      40.800
            10        0.50        10.977     83.448     1316.063       123.670    -25.926         8.303      37.910
            11        0.55        10.494     88.632     1202.815       131.353    -26.981         9.177      34.836
            12        0.60         9.988     90.216     1089.498       133.700    -26.997        10.051      31.700
            13        0.65         9.454     91.800      976.113       136.048    -27.013        10.925      28.562
            14        0.70         8.887     93.384      862.563       138.395    -27.029        11.799      25.421
            15        0.75         8.283     94.968      749.150       140.743    -27.044        12.673      22.278
            16        0.80         7.629     96.552      635.576       143.090    -27.058        13.547      19.132
            17        0.85         6.913     98.136      521.943       145.438    -27.072        14.421      15.983
            18        0.90         6.114     99.720      408.256       147.785    -27.085        15.295      12.829
            19        0.95         5.193    101.304      294.521       150.133    -27.097        16.169       9.667
            20        1.00         4.068    102.888      180.751       152.480    -27.105        17.043       6.479
            21        1.05         2.386    108.576       62.157       160.909    -28.254        17.917       3.159
```

```
                                                     CUBE
SIDE   =    2.000
WEIGHT =    702.8  LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  1.10


 IMPACT VELOCITY EQUALS 20.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
      0.75  0.95  0.95  1.30  2.40  2.87  2.91  3.04


              CONDITIONS AT THE END OF SECTION
                                                              WORK DONE IN SECTION - FOOT POUNDS
 ITERATION PENETRATION    VELOCITY   SHEAR    BODY ENERGY     STATIC     SEDIMENT      BUOYANT     FORM DRAG
  SECTION      FEET        FT/SEC  STRENGTH PSF  FT-LBS       FORCES     INERTIA       FORCES      FORCES

     1         0.05        17.805     5.400    3462.339        8.003     824.897        0.437      108.038
     2         0.10        17.628    16.200    3393.711       24.008     -16.362        1.311       94.845
     3         0.15        17.417    27.000    3313.068       40.014     -19.213        2.185       92.779
     4         0.20        17.173    37.800    3220.180       56.020     -21.999        3.059       90.386
     5         0.25        16.894    48.600    3116.981       72.025     -24.725        3.933       87.673
     6         0.30        16.579    59.400    3001.984       88.031     -27.390        4.807       84.646
     7         0.35        16.228    70.200    2876.278      104.036     -29.996        5.681       81.313
     8         0.40        15.838    81.000    2739.400      120.042     -32.544        6.555       77.680
     9         0.45        15.407    91.800    2592.410      136.048     -35.036        7.429       73.755
    10         0.50        14.932   102.600    2435.[illegible]  152.053     -37.474        8.303       69.543
    11         0.55        14.425   108.[illegible]  2272.[illegible]  162.190     -38.740        9.177       65.115
    12         0.60        13.898   112.[illegible]  2109.[illegible]  166.458     -38.863       10.051       60.608
    13         0.65        13.348   115.[illegible]  1945.[illegible]  170.726     -38.982       10.925       56.086
    14         0.70        12.772   118.000    1781.572      174.995     -39.099       11.799       51.551
    15         0.75        12.168   120.[illegible]  1617.044      179.263     -39.212       12.673       47.001
    16         0.80        11.530   123.[illegible]  1452.[illegible]3  183.531     -39.324       13.547       42.438
    17         0.85        10.853   126.[illegible]  1286.[illegible]  187.799     -39.432       14.421       37.861
    18         0.90        10.129   129.[illegible]  1120.[illegible]  192.067     -39.538       15.295       33.271
    19         0.95         9.347   132.[illegible]   954.[illegible]  196.335     -39.642       16.169       28.667
    20         1.00         8.491   135.[illegible]   787.[illegible]  200.604     -39.743       17.043       24.049
    21         1.05         7.546   136.[illegible]   621.826      202.738     -39.435       17.917       19.439
    22         1.10         6.485   136.[illegible]   459.277      202.738     -38.727       18.791       14.884
    23         1.15         5.238   136.800    299.646      202.738     -38.031       19.665       10.395
    24         1.20         3.617   136.800    142.910      202.738     -37.342       20.539        5.938
CORE USAGE       OBJECT CODE=      8032 BYTES,ARRAY AREA=     4200 BYTES,TOTAL AREA AVAILABLE=   43104  BYTES
COMPILE TIME=     0.69 SEC,EXECUTION TIME=      0.66 SEC,  WATFIV - VERSION 1 LEVEL 1 JANUARY  1970     DATE=  70/281
```

APPENDIX G: COMPUTATION OF THE PENETRATION OF A RECTANGULAR PARALLELEPIPED

```
C DYNAMIC PENETRATION OF AN OBJECT INTO THE OCEAN BOTTOM
C PROGRAM TO CALCULATE SECTION PROPERTIES OF A RECTANGLE
C
C UNITS FEET/POUNDS/SLUGS/SECONDS/
C
C DX        INCREMENT SIZE
C
C BWD       BULK WET DENSITY OF SEDIMENT
C
C BMASS     OBJECT MASS
C
C AMASS()   ADDED MASS PLUS MASS OF DISPLACED SEDIMENT AT SECTION ( )
C
C DMASS( )CHANGE IN AMASS OVER SECTION INDICATED BY SUBSCRIPT
C
C AREA( ) PROJECTED AREA FOR SECTION ( )
C
C CNC       BEARING CAPACITY COEFFICIENT
C
C VOL( )    VOLUME OF SECTION ( )
C
C CFOOT     BEARING CAPACITY CONSTANT DEPENDS ON SHAPE OR AREA
C
C XXX       DEPTH OF PENETRATION
C
C SVOL( ) SUM OF VOLUMES TO SECTION INDICATED
C
C V( )      VELOCITY OF OBJECT AT SECTION ( )
C
C WS( )     WORK DONE BY SEDIMENT IN SECTION ( )
C
C WT        WEIGHT OF OBJECT
C
C G         ACCELERATION OF GRAVITY
C
C SPS       SHEAR STRENGTH OF SEDIMENT
C
C DIM       DIMENSIONS OF THE RECTANGLE BASE
C
C WDRAG     WORK DONE BY DRAG FORCES
C
C WB( )     WORK DONE BY BUOYANCY WHEN SUBMERGING TO SECTION ( )
C
C WBSUB( )WORK DONE BY SUBMERGED SECTION ( )
```

```
C
C US( )     WORK TO SUBMERGE SECTION ( )
C
C SUMSUB()WORK DONE BY SUBMERGED SECTIONS TO SECTION( )
C
C E( )      KINETIC ENERGY OF BODY AT SECTION( )
C
C
       DIMENSION AREA(500),VOL(500),AMASS(500),DMASS(500),SVOL(500),WS(50
      20),WB(500),WBSUB(500),US(500),SUMSUB(500),E(500),V(500)
       DATA PI/3.141593/,G/32.1725/,AREA/500*0.0/,VOL/500*0.0/,AMASS/500*
      20.0/,DMASS/500*0.0/,SVOL/500*0.0/,WS/500*0.0/,WB/500*0.0/,WBSUB/50
      30*0.0/,US/500*0.0/,SUMSUB/500*0.0/,E/500*0.0/,V/500*0.0/
C
C
C
C     INPUT DATA ON OBJECT
C     OBJECT RECTANGLE
      DIM1=2.0
      DIM2=3.0
      WT=1014.75
      BWD=87.402/G
      CFOOT=1.3
      CNC=5.7
C     COHESION OR SHEAR STRENGTH IN PSI EQUALS .3 FOR PROGRAM CHECKOUT
      COH=43.2
C
C     FOR A RECTANGLE USE A COEFFICIENT OF DRAG EQUAL TO 1.0
      CD=1.0
C
C
C     SET INCREMENT
      DX=.05
C
C
C
C
C     CALCULATE THE SECTION PROPERTIES,AVERAGE PROJECTED AREA,VOLUME
C     FIND AREA AT MIDPOINT OF EACH SECTION
C     Y=DISTANCE ABOVE BOTTOM OF RECTANGLE
      Y=DX/2.
      YMAX=DIM1
      Z=DIM1/DX
      N=Z+1.
C     THE ONE ACCOUNTS FOR INTEGER TRUNCATION IN THIS PROBLEM
      AREA(1)=DIM1*DIM2
      DO 100 I=2,N
      AREA(I)=AREA(1)
  100 CONTINUE
```

```
C
C     FOR THIS ANALYSIS THE AREA IS CONSTANT FOR THE REMAINING
C     PENETRATION, THEREFORE SET THE SUCCEEDING AREAS AS FOLLOWS
      DO 200 I=N,100
      AREA(I)=AREA(N)
C     PRINT,AREA(I)
  200 CONTINUE
C
C
C
C     COMPUTE THE VOLUME OF EACH SECTION
C     VOLUME EQUALS AVERAGE AREA TIMES SECTION HEIGHT
C
      DO 300 I=1,100
      VOL(I)=AREA(I)*DX
  300 CONTINUE
C     CHECK VOLUME CALCULATIONS
      HAFVOL=DIM1**2*DIM2
      CVOL=VOL(1)
      DO 350 I=2,N
      CVOL=CVOL+VOL(I)
  350 CONTINUE
C
      ERROR=CVOL-HAFVOL
C     PRINT,CVOL,HAFVOL,ERROR
C
C
C
C
C
C     CALCULATE ADDED MASS, DISPLACED MASS AND CHANGE IN ADDED MASS PLUS
C     DISPLACED MASS FROM SECTION TO SECTION.
C     APPROXIMATE THE RECTANGLE BY USING ONE HALF OF AN ELLIPTICAL PLATE
C     WITH THE SAME AREA AND RATIO OF MAXIMUM AND MINIMUM DIMENSIONS
C     AS THE RECTANGLE.
C     AMASS BECOMES CONSTANT WHEN THE MAXIMUM AREA HAS BEEN REACHED
C     THIS ASSUMES A CAVITY IS FORMED AFTER THE OBJECT PENETRATES PAST
C     ITS MAXIMUM DIMENSION
C     SINCE SEPARATION OCCURS AT IMPACT AMASS REMAINS CONSTANT AND THERE
C     IS NO CONTRIBUTION FROM THE DISPLACED MASS.
C
      K=N+1
      DO 400 I=2,K
C     INTEGERS TRUNCATE SO THERE IS AN APPROXIMATION HERE IN THE NUMBER
C     OF ITERATIONS TAKEN
C     SEE PAGE 421 OF SAUNDERS FOR FORMULAS BELOW
      EK=.51
C     THE ELLIPSE DIMENSIONS ARE
      A=SQRT(DIM2**2/PI)
      B=A/1.5
```

```
      REA=PI*A*B
C     PRINT,A,B,REA
C
      AMASS(I-1)=EK*(2./3.)*BWD*PI*A**2*B
  400 CONTINUE
C
C     AMASS REMAINS THE SAME AFTER THE MAX AREA
C
      DO 450 I=N,100
      AMASS(I)=AMASS(N)
C     PRINT,AMASS(N)
  450 CONTINUE
C
C     COMPUTE CHANGE IN AMASS FROM SECTION TO SECTION
      DMASS(1)=0.0
      DO 500 I=2,N
      DMASS(I)=AMASS(I)-AMASS(I-1)
C     PRINT,DMASS(N)
  500 CONTINUE
C
C
C
C
C     CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C     PER SECTION IF THE SHEAR STRENGTH IS CONSTANT FOR PROGRAM CHECK
C     ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X COHESIONX DX
      CT=CFOOT*CNC
      DO 600 I=1,100
      WS(I)=CT*CCH*AREA(I)*DX
  600 CONTINUE
C
C
C
C
C     CALCULATE WORK DONE BY BUOYANCY

      GAMMA=BWD*G
      WB(1)=(GAMMA*AREA(1)*DX**2)/2.
      SUMSUB(1)=2.0*WB(1)
      DO 700 I=2,N
C
C     WORK TO SUBMERGE SECTION
      US(I)=(GAMMA*AREA(I)*DX**2)/2.
C
C     WORK TO CONTINUE SECTION AFTER SUBMERGING
      WBSUB(I)=2.0*US(I)
C
C     TOTAL WORK OF THE SUBMERGED SECTIONS
      SUMSUB(I)=SUMSUB(I-1)+WBSUB(I)
```

```
C
C     TOTAL WORK DONE SUBMERGING SECTION PLUS THOSE ALREADY SUBMERGED
      WB(I)=US(I)+SUMSUB(I-1)
  700 CONTINUE
C
C     AFTER ALL SECTIONS ARE SUBMERGED WORK BECOMES CONSTANT EQUAL TO
C     SUMSUB(N) PLUS WBSUB(N) FOR EACH FURTHUR INCREMENT
C
      DO 760 I=N,100
      WB(I)=SUMSUB(N)+(I-(N-1))*WBSUB(N)
C     PRINT,WB(I)
  760 CONTINUE
C
C     CHECK WORK TO SUBMERGE
C
      CWB=WB(1)
      DO 800 I=2,N
      CWB=CWB+WB(I)
  800 CONTINUE
C     PRINT,CWB
C
C     ACTUAL WORK BY INTEGRATION IS
C
      X=N*DX
      AWB=(GAMMA)*DIM1*DIM2*X**2/2.
C     PRINT,AWB,X
C
C
C
C
C     PROGRAM TO COMPUTE PENETRATION DEPTH FOLLOWS
C
C     BE ABLE TO DO NNN DIFFERENT VELOCITIES AND SHEAR STRENGTHS
      READ(5,2050) NNN
      WRITE(6,2060)NNN
C
      DO 1000 J=1,NNN
      WRITE(6,2200) DIM1,DIM2,WT,BWD,CD
C
C     READ IN THE VELOCITIES AND SHEAR STRENGTHS
      READ(5,2100) VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40
      WRITE(6,2300)VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40
      WRITE(6,2500)
C
C
C     CALCULATE ORIGINAL ENERGY OF BODY AT INTERFACE
      BMASS=WT/G
      E(1)=BMASS*VO**2/2.
```

```
C
C     CALCULATE POTENTIAL ENERGY FOR EACH INCREMENT
      EP=WT*DX
C
C
C
C     COMPUTE SLOPE OF SHEAR STRENGTH VARIATIONS
      SLOPE1=SS05/.5
      BINT1=0.0
C
      SLOPE2=(SS10-SS05)/.5
      BINT2=-SLOPE2*.5+SS05
C
      SLOPE3=(SS105-SS10)/.5
      BINT3=-SLOPE3*1.+SS10
C
      SLOPE4=(SS20-SS105)/.5
      BINT4=-SLOPE4*1.5+SS105
C
      SLOPE5=(SS205-SS20)/.5
      BINT5=-SLOPE5*2.0+SS20
C
      SLOPE6=(SS30-SS205)/.5
      BINT6=-SLOPE6*2.5+SS205
C
      SLOPE7=(SS305-SS30)/.5
      BINT7=-SLOPE7*3.+SS30
C
      SLOPE8=(SS40-SS305)/.5
      BINT8=-SLOPE8*3.5+SS305
C
C
C     VELOCITY OF SEDIMENT AT INTERFACE IS ALWAYS 0 AT INSTANT OF IMPACT
      V(1)=0.0
      DO 2000 I=1,100
C     SECTION TO COMPUTE SHEAR STRENGTH
C     NOTE THAT THE SHEAR STRENGTH IS COMPUTED IN INCHES THEN CONVERTED
C     TO POUNDS PER SQUARE FOOT FOR THE CALCULATION
C
C     FOR THE RECTANGLE TAKE THE DEPTH FOR THE SHEAR STRENGTH TO BE
C     PENETRATION DEPTH
      DEPTH=I*DX-Y
C     CONVERT THE DEPTH TO INCHES FOR EASY COMPARISON WITH  DATA
      DEPTHI=DEPTH*12.
C
C     SELECT PROPER DEPTH
      IF(DEPTH.LE..5) GO TO 1
C
```

```
      IF((DEPTH.LE.1.0).AND.(DEPTH.GT.0.5)) GO TO 2
      IF((DEPTH.LE.1.5).AND.(DEPTH.GT.1.0)) GO TO 3
      IF((DEPTH.LE.2.0).AND.(DEPTH.GT.1.5)) GO TO 4
      IF((DEPTH.LE.2.5).AND.(DEPTH.GT.2.0)) GO TO 5
      IF((DEPTH.LT.3.0).AND.(DEPTH.GT.2.5)) GO TO 6
      IF((DEPTH.LE.3.5).AND.(DEPTH.GT.3.0)) GO TO 7
      IF((DEPTH.LE.4.0).AND.(DEPTH.GT.3.5)) GO TO 8
C
C     FOR DEPTHS LARGER THAN LAST SHEAR STRENGTH TAKE THE ARITHMETIC
C     AVERAGE OF THE LAST THREE AND CALL IT CONSTANT
C
      IF(DEPTH.GT.4.0) GO TO 9
C
C     FORMULAS FOR SHEAR STRENGTH FOLLOW
C     LINEAR VARIATION BETWEEN MEASURED POINTS IS ASSUMED
C
    1 SSS=SLOPE1*DEPTH
      GO TO 10
    2 SSS=SLOPE2*DEPTH+BINT2
      GO TO 10
    3 SSS=SLOPE3*DEPTH+BINT3
      GO TO 10
    4 SSS=SLOPE4*DEPTH+BINT4
      GO TO 10
    5 SSS=SLOPE5*DEPTH+BINT5
      GO TO 10
    6 SSS=SLOPE6*DEPTH+BINT6
      GO TO 10
    7 SSS=SLOPE7*DEPTH+BINT7
      GO TO 10
    8 SSS=SLOPE8*DEPTH+BINT8
      GO TO 10
C
    9 SSS=(SS30+SS305+SS40)/3.
C
C     SPS IS THE SHEAR STRENGTH IN POUNDS PER SQUARE FOOT
   10 SPS=SSS*144.
C     CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C     ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X SPS X DX
      CT=CFOOT*CNC
      WS(I)=CT*SPS*AREA(I)*DX
      AMASS1=(AMASS(I)*V(I)**2/2.)
      VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I))/(BMASS+DMASS(I)+AMASS(I))
      IF (VELOSQ.LE.0.0)GO TO 1000
      V(I+1)=SQRT(VELOSQ)
C
C
C     SECTION TO COMPUTE THE WORK DONE BY DRAG
```

```
C      APPROXIMATE AVERAGE VELOCITY OVER A SECTION BY NEGLECTING THE DRAG
C      FIRST TIME OVER THE SECTION, AS DONE ABOVE
       VAVG=(V(I)+V(I+1))/2.
       IF(I.EQ.1) VAVG=(VO+V(I+1))/2.
       WDRAG=.5*BWD*CD*AREA(I)*DX*VAVG**2
C
       VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I)-WDRAG)/(BMASS+DMASS(I)+AMAS
      2S(I))
       IF (VELOSQ.LE.0.0)GO TO 1000
       V(I+1)=SQRT(VELOSQ)
C
C      CALCULATE E AT NEXT SECTION
       E(I+1)=BMASS*V(I+1)**2/2.
C
C      CALCULATE ENERGY DISSIPATED BY ADDED MASS EFFECTS, EAM
       EAM=.5*(AMASS(I)*V(I+1)**2-2.0*AMASS1+DMASS(I)*V(I+1)**2)
C
C      COMPUTE PENETRATION DEPTH
       XXX=I*DX
C
C      PRINT THE SECTION, DEPTH OF PENETRATION, VELOCITY AT THE END OF
C      SECTION, SHEAR STRENGTH IN SECTION, BODY ENERGY AT END OF SECTION,
C      WORK DONE BY   SEDIMENT, ADDED MASS PLUS DISPLACED MASS, BUOYANCY,
C      AND DRAG
C
       WRITE(6,2600) I,XXX,V(I+1),SPS,E(I+1),WS(I),EAM,WB(I),WDRAG
 2000  CONTINUE
 1000  CONTINUE
 2050  FORMAT(I5)
 2060  FORMAT(' ',I3)
 2100  FORMAT(F5.1,8F5.2)
 2200  FORMAT('1',60X,'RECTANGLE'//9X,'WIDTH = ',F7.2,'FEET'/9X,'LENGTH
      2= ',F7.2,'FEET'/9X,'WEIGHT = ',F7.2,' LBS'/9X,'BULK WET DENSITY =
      3',F5.2,' SLUGS PER CUBIC FOOT'/9X,'DRAG COEFFICIENT = ',F5.2///)
 2300  FORMAT(' ',10X,'IMPACT VELOCITY EQUALS',F5.1///10X,'SEDIMENT SHEAR
      2 STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE'//15X,8F6.2//)
 2500  FORMAT('0',28X,'CONDITIONS AT THE END OF SECTION',19X,'WORK DONE I
      2N SECTION - FOOT POUNDS'///16X,'ITERATION',1X,'PENETRATION',4X,'VE
      3LOCITY',3X,'SHEAR',5X,'BODY ENERGY',6X,'STATIC',4X,'SEDIMENT',5X,'
      4BUOYANT',3X,'FORM DRAG'/17X,'SECTION',6X,'FEET',8X,'FT/SEC',2X,'ST
      5RENGTH PSF',4X,'FT-LBS',7X,'FORCES',4X,'INERTIA',6X,'FORCES',4X,'F
      6ORCES'//)
 2600  FORMAT(' ',16X,I3,3X,F12.2,7F12.3)
       STOP
       END
```

```
IMPACT VELOCITY EQUALS  0.0                                     RECTANGLE

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE WIDTH =     2.00FEET
     0.50  0.71  1.04  1.34  1.74  2.12  2.78  2.87              LENGTH  =      3.00FEET
                                                                 WEIGHT = 1014.75 LBS
                                                                 BULK WET DENSITY =  2.72 SLUGS PER CUBIC FOOT
                                                                 DRAG COEFFICIENT =  1.00
                 CONDITIONS AT THE END OF SECTION
                                                                     WORK DONE IN SECTION - FOOT POUNDS

   ITERATION PENETRATION    VELOCITY   SHEAR     BODY ENERGY     STATIC      SEDIMENT       BUOYANT     FORM DRAG
    SECTION     FEET         FT/SEC  STRENGTH PSF    FT-LBS      FORCES      INERTIA        FORCES      FORCES

      1         0.05         1.431     3.600       32.272        8.003        9.598         0.656        0.210
      2         0.10         1.790    10.800       50.536       24.008        5.432         1.967        1.066
      3         0.15         1.871    18.000       55.213       40.014        1.391         3.278        1.379
      4         0.20         1.719    25.200       46.582       56.020       -2.567         4.589        1.327
      5         0.25         1.257    32.400       24.923       72.025       -6.441         5.900        0.913


IMPACT VELOCITY EQUALS  5.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
     0.35  1.02  1.37  2.68  2.99  3.02  2.95  2.77


                 CONDITIONS AT THE END OF SECTION
                                                                     WORK DONE IN SECTION - FOOT POUNDS

   ITERATION PENETRATION    VELOCITY   SHEAR     BODY ENERGY     STATIC      SEDIMENT       BUOYANT     FORM DRAG
    SECTION     FEET         FT/SEC  STRENGTH PSF    FT-LBS      FORCES      INERTIA        FORCES      FORCES

      1         0.05         4.581     2.520      330.886        5.602       98.405         0.656        9.449
      2         0.10         4.702     7.560      348.690       16.806        5.295         1.967        8.865
      3         0.15         4.755    12.600      356.588       28.010        2.349         3.278        9.203
      4         0.20         4.743    17.640      354.778       39.214       -0.539         4.589        9.283
      5         0.25         4.667    22.680      343.453       50.418       -3.368         5.900        9.112
      6         0.30         4.524    27.720      322.804       61.622       -6.141         7.211        8.694
      7         0.35         4.310    32.760      293.019       72.825       -8.858         8.522        8.033
      8         0.40         4.015    37.800      254.278       84.029      -11.521         9.833        7.136
      9         0.45         3.621    42.840      206.765       95.233      -14.130        11.144        6.004
     10         0.50         3.091    47.880      150.657      106.437      -16.686        12.455        4.639
     11         0.55         2.284    55.224       82.237      122.763      -20.348        13.766        2.977
```

```
WIDTH =     2.00FEET                              RECTANGLE
LENGTH  =      3.00FEET
WEIGHT = 1014.75 LBS
BULK WET DENSITY =  2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  1.00

 IMPACT VELOCITY EQUALS 10.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
      0.51  0.68  0.71  1.17  1.74  2.07  1.95  3.13

           CONDITIONS AT THE END OF SECTION
                                                                  WORK DONE IN SECTION - FOOT POUNDS
   ITERATION PENETRATION    VELOCITY   SHEAR      BODY ENERGY
    SECTION     FEET         FT/SEC  STRENGTH PSF    FT-LBS      STATIC     SEDIMENT      BUOYANT    FORM DRAG
                                                                 FORCES     INERTIA       FORCES     FORCES
      1         0.05         8.795       3.672     1219.820        8.163     362.771       0.656      36.373
      2         0.10         8.774      11.016     1214.055       24.489      -1.714       1.967      31.761
      3         0.15         8.705      18.360     1194.946       40.814      -5.683       3.278      31.437
      4         0.20         8.587      25.704     1162.759       57.140      -9.572       4.589      30.767
      5         0.25         8.419      33.048     1117.755       73.466     -13.383       5.900      29.759
      6         0.30         8.199      40.392     1060.190       89.791     -17.120       7.211      28.420
      7         0.35         7.924      47.736      990.314      106.117     -20.781       8.522      26.755
      8         0.40         7.589      55.080      908.373      122.443     -24.362       9.833      24.771
      9         0.45         7.187      62.424      814.609      138.768     -27.885      11.144      22.473
     10         0.50         6.706      69.768      709.259      155.094     -31.331      12.455      19.869
     11         0.55         6.151      74.664      596.706      165.978     -33.473      13.766      17.018
     12         0.60         5.524      77.112      481.248      171.420     -34.337      15.077      14.034
     13         0.65         4.797      79.560      362.948      176.862     -35.182      16.388      10.970
     14         0.70         3.916      82.008      241.869      182.304     -36.009      17.699       7.821
     15         0.75         2.737      84.456      118.096      187.746     -36.810      19.010       4.564
```

```
WIDTH =     2.00FEET                                    RECTANGLE
LENGTH  =     3.00FEET
WEIGHT = 1014.75 LBS
BULK WET DENSITY =  2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  1.00

 IMPACT VELOCITY EQUALS 15.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
      0.38  0.69  0.69  1.56  2.00  2.75  2.80  2.96

               CONDITIONS AT THE END OF SECTION
                                                                     WORK DONE IN SECTION - FOOT POUNDS
  ITERATION PENETRATION    VELOCITY    SHEAR      BODY ENERGY
   SECTION     FEET         FT/SEC   STRENGTH PSF    FT-LBS       STATIC       SEDIMENT        BUOYANT     FORM DRAG
                                                                  FORCES       INERTIA         FORCES      FORCES

     1          0.05        13.100   [illegible]   2706.221        6.082   [illegible]          0.656       81.305
     2          0.10        13.025   [illegible]   [illegible]   [illegible]  [illegible]        1.967       70.231
     3          0.15     [illegible] [illegible]   [illegible]   [illegible]  [illegible]     [illegible]  [illegible]
     4          0.20     [illegible] [illegible]   [illegible]   [illegible]  [illegible]        4.589     [illegible]
     5       [illegible] [illegible] [illegible]   [illegible]   [illegible]  [illegible]     [illegible]  [illegible]
     6       [illegible] [illegible] [illegible]   [illegible]   [illegible]  [illegible]     [illegible]  [illegible]
     7       [illegible] [illegible] [illegible]     2381.277    [illegible]  [illegible]     [illegible]  [illegible]
     8          0.40     [illegible] [illegible]   [illegible]   [illegible]  [illegible]        8.522     [illegible]
     9          0.45     [illegible] [illegible]   [illegible]   [illegible]  [illegible]        9.833     [illegible]
    10          0.50     [illegible] [illegible]   [illegible]   [illegible]  [illegible]       11.144     [illegible]
    11          0.55     [illegible] [illegible]   [illegible]   [illegible]  [illegible]       12.455       56.101
    12          0.60     [illegible] [illegible]   [illegible]   [illegible]  [illegible]       13.766     [illegible]
    13          0.65     [illegible] [illegible]   [illegible]   [illegible]  [illegible]       15.077     [illegible]
    14          0.70     [illegible] [illegible]   [illegible]     146.451    [illegible]       16.388       47.235
    15          0.75     [illegible]    70.344     [illegible]   [illegible]  [illegible]     [illegible]  [illegible]
    16       [illegible] [illegible] [illegible]     1343.962    [illegible]    -41.831         19.010     [illegible]
    17       [illegible] [illegible] [illegible]   [illegible]   [illegible]  [illegible]       20.321     [illegible]
    18       [illegible] [illegible] [illegible]   [illegible]   [illegible]    -45.276         21.632     [illegible]
    19          0.95     [illegible] [illegible]   [illegible]   [illegible]  [illegible]       22.943       25.186
    20       [illegible] [illegible] [illegible]      724.163    [illegible]  [illegible]       24.254     [illegible]
    21          1.05     [illegible] [illegible]      559.441      220.877    [illegible]       25.565       16.692
    22          1.10     [illegible] [illegible]      397.016      220.877      -48.305         26.876       12.402
    23          1.15     [illegible] [illegible]   [illegible]     220.877      -47.630         28.187        8.149
    24          1.20     [illegible] [illegible]       78.998      220.877      -46.948         29.498        3.860
                                                                                                30.809
```

```
                                                    RECTANGLE
WIDTH =     2.00FEET
LENGTH  =      3.00FEET
WEIGHT = 1014.75 LBS
BULK WET DENSITY =  2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  1.00


 IMPACT VELOCITY EQUALS 15.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
       0.40  0.33  0.35  0.69  1.74  2.70  2.75  2.95


               CONDITIONS AT THE END OF SECTION
                                                                 WORK DONE IN SECTION - FOOT POUNDS

      ITERATION PENETRATION     VELOCITY   SHEAR      BODY ENERGY       STATIC      SEDIMENT      BUOYANT      FORM DRAG
       SECTION      FEET         FT/SEC  STRENGTH PSF   FT-LBS           FORCES      INERTIA       FORCES       FORCES

          1          0.05        13.099   [illegible]   2705.977          6.402      804.751        0.656        81.302
          2          0.10        13.022   [illegible]   2674.643         19.207       -9.318        1.967        70.215
          3          0.15        12.924   [illegible]   2633.160         32.011      -12.337        3.279        69.265
          4          0.20        12.791   [illegible]   2581.732         44.816      -15.294        4.589        67.053
          5          0.25        12.647   [illegible]   2520.553         57.620      -18.193        5.900        65.583
          6          0.30        12.461   [illegible]   2449.830         70.425      -21.034        7.211        63.862
          7          0.35        12.253   [illegible]   2365.740         83.229      -23.810        8.522        62.893
          8          0.40        12.025   [illegible]   2280.479         96.034      -26.547        9.833        60.693
          9          0.45        11.763   [illegible]   2187.215        108.838      -29.222       11.144        58.235
         10          0.50        11.471   [illegible]   2076.141        121.643      -31.843       12.455        55.554
         11          0.55        11.165   [illegible]   1965.170        126.924      -32.705       13.766        52.721
         12          0.60        10.851   [illegible]   1850.099        124.584      -31.943       15.077        49.888
         13          0.65        10.546   [illegible]   1753.870        122.443      -30.997       16.388        47.131
         14          0.70        10.236   [illegible]   1652.427        120.202      -30.169       17.699        44.447
         15          0.75         9.926   [illegible]   1553.714        117.961      -29.357       19.010        41.835
         16          0.80         9.614   [illegible]   1457.677        115.720      -28.561       20.321        39.293
         17          0.85         9.301   [illegible]   1364.263        113.480      -27.781       21.632        36.821
         18          0.90         8.986   [illegible]   1273.419        111.239      -27.017       22.943        34.416
         19          0.95         8.669   [illegible]   1185.093        108.998      -26.258       24.254        32.077
         20          1.00         8.349   [illegible]   1099.237        106.757      -25.534       25.565        29.804
         21          1.05         8.021   [illegible]   1014.701        105.957      -25.141       26.876        27.580
         22          1.10         7.681   [illegible]    930.360        106.597      -25.033       28.187        25.375
         23          1.15         7.325   [illegible]    846.211        107.237      -25.026       29.498        23.176
         24          1.20         6.952   [illegible]    762.250        107.878      -24.970       30.809        20.981
         25          1.25         6.559   [illegible]    678.473        108.518      -24.915       32.120        18.790
         26          1.30         6.142   [illegible]    594.877        109.158      -24.861       33.431        16.604
         27          1.35         5.695   [illegible]    511.459        109.798      -24.808       34.742        14.422
         28          1.40         5.211   [illegible]    428.217        110.439      -24.756       36.053        12.244
         29          1.45         4.678   [illegible]    345.146        111.079      -24.705       37.364        10.068
         30          1.50         4.078   [illegible]    262.247        111.719      -24.654       38.675         7.895
         31          1.55         3.337   [illegible]    175.617        117.481      -25.764       39.986         5.664
         32          1.60         2.273   [illegible]     81.452        129.364      -28.005       41.297         3.246
```

```
                                             RECTANGLE
WIDTH =      2.00FEET
LENGTH  =       3.00FEET
WEIGHT = 1014.75 LBS
BULK WET DENSITY =  2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  1.00

 IMPACT VELOCITY EQUALS 20.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
      0.26  0.35  0.95  1.10  1.56  2.45  2.53  2.44

                  CONDITIONS AT THE END OF SECTION                        WORK DONE IN SECTION - FOOT POUNDS

    ITERATION PENETRATION     VELOCITY   SHEAR     BODY ENERGY         STATIC      SEDIMENT      BUOYANT     FORM DRAG
     SECTION     FEET          FT/SEC  STRENGTH PSF   FT-LBS           FORCES      INERTIA       FORCES      FORCES

        1          0.05        17.421       1.872     4786.410          4.161      1423.468       0.656      144.193
        2          0.10        17.299       5.616     4718.758         12.484       -20.120       1.967      124.039
        3          0.15        17.162       9.360     4645.102         20.907       -21.905       3.278      122.195
        4          0.20        17.015      13.104     4565.555         29.130       -23.657       4.589      120.196
        5          0.25        16.855      16.848     4480.244    [illegible]       -25.371       5.900      118.045
        6          0.30        16.683  [illegible]  [illegible]    [illegible]       -27.053       7.211      115.745
        7          0.35        16.494  [illegible]    4292.773    [illegible]       -28.702       8.522      113.299
        8          0.40        16.302  [illegible]    4190.144         62.422       -30.314       9.833      110.709
        9          0.45        16.097  [illegible]  [illegible]    [illegible]       -31.896      11.144      107.979
       10          0.50        15.868  [illegible]  [illegible]    [illegible]       -33.446      12.455      105.111
       11          0.55        15.636  [illegible]  [illegible]    [illegible]       -34.347      13.766      102.136
       12          0.60        15.398  [illegible]    3739.244         87.551       -34.615      15.077       99.110
       13          0.65        15.155  [illegible]    3621.971    [illegible]       -34.877      16.388       96.061
       14          0.70        14.906  [illegible]  [illegible]    [illegible]       -35.133      17.699       92.989
       15          0.75        14.650  [illegible]  [illegible]    [illegible]       -35.385      19.010       89.394
       16          0.80        14.389  [illegible]  [illegible]    [illegible]       -35.632      20.321       86.778
       17          0.85        14.120  [illegible]  [illegible]    [illegible]       -35.873      21.632       83.640
       18          0.90        13.845  [illegible]  [illegible]    [illegible]       -36.109      22.943       80.481
       19          0.95        13.562  [illegible]  [illegible]    [illegible]       -36.341      24.254       77.302
       20          1.00        13.272  [illegible]  [illegible]    [illegible]       -36.569      25.565       74.102
       21          1.05        12.958  [illegible]  [illegible]        121.642       -38.644      26.876       70.801
       22          1.10        12.603      63.360     2504.839        140.849       -42.531      28.187       67.237
       23          1.15        12.205      72.000     2340.072        160.056       -46.339      29.498       63.335
       24          1.20        11.759  [illegible]  [illegible]    [illegible]       -50.072      30.809       59.101
       25          1.25        11.262  [illegible]  [illegible]    [illegible]       -53.730      32.120       54.543
       26          1.30        10.705      97.920     1807.319        217.675       -57.315      33.431       49.664
       27          1.35        10.081     106.560  [illegible]    [illegible]       -60.828      34.742       44.473
       28          1.40         9.377     115.200  [illegible]        256.089       -64.270      36.053       38.974
       29          1.45         8.574     123.840  [illegible]        275.296       -67.643      37.364       33.171
       30          1.50         7.641     132.480  [illegible]    [illegible]       -70.948      38.675       27.068
       31          1.55         6.551  [illegible]  [illegible]    [illegible]       -72.549      39.986       20.740
       32          1.60         5.240     140.040  [illegible]        311.309       -72.479      41.297       14.322
       33          1.65         3.467     142.200      189.591        316.110       -72.390      42.609        7.821
```

APPENDIX H: COMPUTATION OF THE PENETRATION OF A CONE

```
C DYNAMIC PENETRATION OF AN OBJECT INTO THE OCEAN BOTTOM
C PROGRAM TO CALCULATE SECTION PROPERTIES OF A CONE
C
C UNITS FEET/POUNDS/SLUGS/SECONDS/
C
C DX        INCREMENT SIZE
C
C BWD       BULK WET DENSITY OF SEDIMENT
C
C BMASS     OBJECT MASS
C
C AMASS()   ADDED MASS PLUS MASS OF DISPLACED SEDIMENT AT SECTION ( )
C
C DMASS( )CHANGE IN AMASS OVER SECTION INDICATED BY SUBSCRIPT
C
C AREA( )   PROJECTED AREA FOR SECTION ( )
C
C CNC       BEARING CAPACITY COEFFICIENT
C
C VOL( )    VOLUME OF SECTION ( )
C
C CFOOT     BEARING CAPACITY CONSTANT DEPENDS ON SHAPE OF AREA
C
C XXX       DEPTH OF PENETRATION
C
C SVOL( )   SUM OF VOLUMES TO SECTION INDICATED
C
C V( )      VELOCITY OF OBJECT AT SECTION ( )
C
C WS( )     WORK DONE BY SEDIMENT IN SECTION ( )
C
C WT        WEIGHT OF OBJECT
C
C G         ACCELERATION OF GRAVITY
C
C SPS       SHEAR STRENGTH OF SEDIMENT
C
C RAD       RADIUS
C
C DIM       LENGTH OF CONE
C
C WDRAG     WORK DONE BY DRAG FORCES
C
C WB( )     WORK DONE BY BUOYANCY WHEN SUBMERGING TO SECTION ( )
C
```

```
C WBSUB( )WORK DONE BY SUBMERGED SECTION ( )
C
C US( )    WORK TO SUBMERGE SECTION ( )
C
C SUMSUB()WORK DONE BY SUBMERGED SECTIONS TO SECTION( )
C
C E( )     KINETIC ENERGY OF BODY AT SECTION( )
C
C
      DIMENSION AREA(500),VOL(500),AMASS(500),DMASS(500),SVOL(500),WS(50
     20),WB(500),WBSUB(500),US(500),SUMSUB(500),E(500),V(500)
      DATA PI/3.141593/,G/32.1725/,AREA/500*0.0/,VOL/500*0.0/,AMASS/500*
     20.0/,DMASS/500*0.0/,SVOL/500*0.0/,WS/500*0.0/,WB/500*0.0/,WBSUB/50
     30*0.0/,US/500*0.0/,SUMSUB/500*0.0/,E/500*0.0/,V/500*0.0/
C
C
C
C     INPUT DATA ON OBJECT
C     OBJECT CONE
      RAD=35.375/24.
      DIM=5.50
      WT=1127.
      BWD=87.402/G
      CFOOT=1.
C     THE CONE'S ANGLE AT THE TIP IS 30 DEGREES
      CNC=4.7
C     COHESION OR SHEAR STRENGTH IN PSI EQUALS .3
      COH=43.2
C
C     FOR A CONE USE A COEFFICIENT OF DRAG EQUAL TO 0.3
      CD=0.3
C
C
C     SET INCREMENT
      DX=.05
C
C
C
C     CALCULATE THE SECTION PROPERTIES,AVERAGE PROJECTED AREA,VOLUME
C     FIND AREA AT MIDPOINT OF EACH SECTION
C     Y=DISTANCE ABOVE POINT OF A CONE
      Y=DX/2.
      YMAX=DIM
      Z=DIM/DX
      N=Z+1.
C     THE ONE ACCOUNTS FOR INTEGER TRUNCATION IN THIS PROBLEM
C     FIND HALF THE ANGLE AT THE TIP OF THE CONE
      ALFA=ATAN(RAD/DIM)
```

```
      RAA=TAN(ALFA)*(DX-Y)
      AREA(I)=PI*RAA**2
      DO 100 I=2,N
      RAA=TAN(ALFA)*(I*DX-Y)
      AREA(I)=PI*RAA**2
  100 CONTINUE
C
C     FOR THIS ANALYSIS AFTER THE AREA HAS BECOME A MAXIMUM IT WILL BE
C     CONSTANT FOR THE REMAINING PENETRATION THEREFORE SET SUCCEEDING
C     AREAS AS FOLLOWS
      DO 200 I=N,500
      AREA(I)=AREA(N)
  200 CONTINUE
C
C     COMPUTE THE VOLUME OF EACH SECTION
C     VOLUME EQUALS AVERAGE AREA TIMES SECTION HEIGHT
C
      DO 300 I=1,500
      VOL(I)=AREA(I)*DX
  300 CONTINUE
C
C     CHECK VOLUME CALCULATIONS
      HAFVOL=PI*RAD**2*DIM/3.
      CVOL=VOL(1)
      DO 350 I=2,N
      CVOL=CVOL+VOL(I)
  350 CONTINUE
C
      ERROR=CVOL-HAFVOL
      PRINT,CVOL,HAFVOL,ERROR
C
C
C
C
C     CALCULATE ADDED MASS, DISPLACED MASS AND CHANGE IN ADDED MASS PLUS
C     DISPLACED MASS FROM SECTION TO SECTION.
C     APPROXIMATE ADDED MASS BY USING ONE HALF OF A PROLATE ELLIPSOID.
C     AMASS BECOMES CONSTANT WHEN THE MAXIMUM AREA HAS BEEN REACHED.
C
      SUMVOL=0.0
      K=N+1
C     INTEGERS TRUNCATE SO THERE IS AN APPROXIMATION HERE IN THE NUMBER
C     OF ITERATIONS TAKEN
      DO 400 I=2,K
C     SEE PAGE 421 OF SAUNDERS FOR FORMULAS BELOW
C     NOW ADDED MASS,DESIGNATE SOME NEW VARIABLES
      EK=0.095
      A=(I-1)*DX-Y
      B=TAN(ALFA)*A
```

```
      AMASS(I-1)=BWD*EK*(2./3.)*PI*A*B**2
C     ADD DISPLACED VOL AT THE SAME TIME
C
C     SUM THE VOLUMES BEFORE ADDING
C
      SUMVOL=SUMVOL+VOL(I-1)
C     SUMVOL AT END OF DO LOOP SHOULD EQUAL HAFVOL
C
      AMASS(I-1)=AMASS(I-1)+BWD*SUMVOL
  400 CONTINUE
C
C     CHECK ADDED MASS BY COMPARING LAST INCREMENT TO ONE HALF ELLIPSOID
C
      HAMAS=BWD*(PI*RAD**2*DIM*EK*(2./3.)+PI*RAD**2*DIM/3.)
      ERROR=HAMAS-AMASS(N)
C     PRINT,HAMAS,AMASS(N),ERROR
C
      DO 450 I=N,500
      AMASS(I)=AMASS(N)
  450 CONTINUE
C
C     COMPUTE CHANGE IN AMASS FROM SECTION TO SECTION
      DMASS(1)=0.0
      DO 500 I=2,N
      DMASS(I)=AMASS(I)-AMASS(I-1)
  500 CONTINUE
C
C     SUM DMASS, IT SHOULD BE CLOSE TO AMASS(N)
C
      CDMASS=DMASS(1)
      DO 550 I=2,N
      CDMASS=CDMASS+DMASS(I)
  550 CONTINUE
C     PRINT,CDMASS,AMASS(N)
C
C
C
C     FOR THE ORIGINAL PROGRAM CHECKOUT
C     CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C     PER SECTION IF THE SHEAR STRENGTH IS CONSTANT OVER THE DEPTH
C     ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X COHESIONX DX
      CT=CFOOT*CNC
      DO 600 I=1,500
      WS(I)=CT*COH*AREA(I)*DX
  600 CONTINUE
C
C
C
```

```
C     CALCULATE WORK DONE BY BUOYANCY
C
      GAMMA=BWD*G
      WB(1)=(GAMMA*AREA(1)*DX**2)/2.
      SUMSUB(1)=2.0*WB(1)
      DO 700 I=2,N
C
C     WORK TO SUBMERGE SECTION
      US(I)=(GAMMA*AREA(I)*DX**2)/2.
C
C     WORK TO CONTINUE SECTION AFTER SUBMERGING
      WBSUB(I)=2.0*US(I)
C
C     TOTAL WORK OF THE SUBMERGED SECTIONS
      SUMSUB(I)=SUMSUB(I-1)+WBSUB(I)
C
C     TOTAL WORK DONE SUBMERGING SECTION PLUS THOSE ALREADY SUBMERGED
      WB(I)=US(I)+SUMSUB(I-1)
  700 CONTINUE
C
C     AFTER ALL SECTIONS ARE SUBMERGED WORK BECOMES CONSTANT EQUAL TO
C     SUMSUB(N) PLUS WBSUB(N) FOR EACH FURTHUR INCREMENT.
C     THIS ASSUMES A CAVITY IS FORMED AFTER THE OBJECT PENETRATES PAST
C     ITS MAXIMUM DIMENSION.
C
      DO 760 I=N,500
      WB(I)=SUMSUB(N)+(I-(N-1))*WBSUB(N)
  760 CONTINUE
C
C     CHECK WORK TO SUBMERGE
C
      CWB=WB(1)
      DO 800 I=2,N
      CWB=CWB+WB(I)
  800 CONTINUE
      PRINT,CWB
C
C
C
C
C
C     PROGRAM TO COMPUTE PENETRATION DEPTH FOLLOWS
C
C     BE ABLE TO DO NNN DIFFERENT VELOCITIES AND SHEAR STRENGTHS
      READ(5,2050) NNN
      WRITE(6,2060)NNN
C
      DO 1000 J=1,NNN
      WRITE(6,2200) RAD,DIM,WT,BWD,CD
```

```
C
C      READ IN THE VELOCITIES AND SHEAR STRENGTHS
       READ(5,2100) VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40,SS405,
      2SS500,SS505,SS600
       WRITE(6,2300)VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40,SS405,
      2SS500,SS505,SS600
       WRITE(6,2500)
C
C
C      CALCULATE ORIGINAL ENERGY OF BODY AT INTERFACE
       BMASS=WT/G
       E(1)=BMASS*VO**2/2.
C
C      CALCULATE POTENTIAL ENERGY FOR EACH INCREMENT
       EP=WT*DX
C
C
C
C      COMPUTE SLOPE OF SHEAR STRENGTH VARIATIONS
C
       SLOPE1=SS05/.5
       BINT1=0.0
C
       SLOPE2=(SS10-SS05)/.5
       BINT2=-SLOPE2*.5+SS05
C
       SLOPE3=(SS105-SS10)/.5
       BINT3=-SLOPE3*1.+SS10
C
       SLOPE4=(SS20-SS105)/.5
       BINT4=-SLOPE4*1.5+SS105
C
       SLOPE5=(SS205-SS20)/.5
       BINT5=-SLOPE5*2.0+SS20
C
       SLOPE6=(SS30-SS205)/.5
       BINT6=-SLOPE6*2.5+SS205
C
       SLOPE7=(SS305-SS30)/.5
       BINT7=-SLOPE7*3.+SS30
C
       SLOPE8=(SS40-SS305)/.5
       BINT8=-SLOPE8*3.5+SS305
C
       SLOPE9=(SS405-SS40)/.5
       BINT9=-SLOPE9*4.0+SS40
C
       SLOPEA=(SS500-SS405)/.5
       BINTA=-SLOPEA*4.5+SS405
```

```
C
      SLOPEB=(SS505-SS500)/.5
      BINTB=-SLOPEB*5.0+SS500
C
      SLOPEC=(SS600-SS505)/.5
      BINTC=-SLOPEC*5.5+SS505
C
C     VELOCITY OF SEDIMENT AT INTERFACE IS ALWAYS 0 AT INSTANT OF IMPACT
      V(1)=0.0
      DO 2000 I=1,500
C     SECTION TO COMPUTE SHEAR STRENGTH
C     NOTE THAT THE SHEAR STRENGTH IS COMPUTED IN INCHES THEN CONVERTED
C     TO POUNDS PER SQUARE FOOT FOR THE CALCULATION
C
C     FOR THE CONE TAKE THE DEPTH FOR SHEAR STRENGTH TO BE THE
C     PENETRATION DEPTH MINUS ONE HALF THE PENETRATION DEPTH
      DEPTH=I*DX-Y-(I*DX-Y)/2.
C     WHEN THE DEPTH OF PENETRATION EQUALS ONE HALF THE LENGTH OF THE
C     CONE THE DEPTH FOR SHEAR STRENGTHS EQUALS THE PENETRATION DEPTH
C     MINUS ONE HALF THE LENGTH
      IF((I*DX-Y).GT.DIM) DEPTH=I*DX-Y-DIM/2.
C
C     CONVERT THE DEPTH TO INCHES FOR EASY COMPARISON WITH  DATA
      DEPTHI=DEPTH*12.
C
C     SELECT PROPER DEPTH
      IF(DEPTH.LE..5) GO TO 1
C
      IF((DEPTH.LE.1.0).AND.(DEPTH.GT.0.5)) GO TO 2
      IF((DEPTH.LE.1.5).AND.(DEPTH.GT.1.0)) GO TO 3
      IF((DEPTH.LE.2.0).AND.(DEPTH.GT.1.5)) GO TO 4
      IF((DEPTH.LE.2.5).AND.(DEPTH.GT.2.0)) GO TO 5
      IF((DEPTH.LT.3.0).AND.(DEPTH.GT.2.5)) GO TO 6
      IF((DEPTH.LE.3.5).AND.(DEPTH.GT.3.0)) GO TO 7
      IF((DEPTH.LE.4.0).AND.(DEPTH.GT.3.5)) GO TO 8
      IF((DEPTH.LE.4.5).AND.(DEPTH.GT.4.0)) GO TO 9
      IF((DEPTH.LE.5.0).AND.(DEPTH.GT.4.5)) GO TO 11
      IF((DEPTH.LE.5.5).AND.(DEPTH.GT.5.0)) GO TO 12
      IF((DEPTH.LE.6.0).AND.(DEPTH.GT.5.5)) GO TO 13
C
C     FOR DEPTHS LARGER THAN LAST SHEAR STRENGTH TAKE THE ARITHMETIC
C     AVERAGE OF THE LAST THREE AND CALL IT CONSTANT
C
      IF(DEPTH.GT.6.0) GO TO 14
C
C     FORMULAS FOR SHEAR STRENGTH FOLLOW
C     LINEAR VARIATION BETWEEN MEASURED POINTS IS ASSUMED
C
```

```
    1 SSS=SLOPE1*DEPTH
      GO TO 10
    2 SSS=SLOPE2*DEPTH+BINT2
      GO TO 10
    3 SSS=SLOPE3*DEPTH+BINT3
      GO TO 10
    4 SSS=SLOPE4*DEPTH+BINT4
      GO TO 10
    5 SSS=SLOPE5*DEPTH+BINT5
      GO TO 10
    6 SSS=SLOPE6*DEPTH+BINT6
      GO TO 10
    7 SSS=SLOPE7*DEPTH+BINT7
      GO TO 10
    8 SSS=SLOPE8*DEPTH+BINT8
      GO TO 10
    9 SSS=SLOPE9*DEPTH+BINT9
      GO TO 10
   11 SSS=SLOPEA*DEPTH+BINTA
      GO TO 10
   12 SSS=SLOPEB*DEPTH+BINTB
      GO TO 10
   13 SSS=SLOPEC*DEPTH+BINTC
      GO TO 10
   14 SSS=(SS500+SS505+SS600)/3.
C
C     SPS IS THE SHEAR STRENGTH IN POUNDS PER SQUARE FOOT
   10 SPS=SSS*144.
C     CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C     ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X SPS X DX
      CT=CFOOT*CNC
      WS(I)=CT*SPS*AREA(I)*DX
      AMASS1=(AMASS(I)*V(I)**2/2.)
      VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I))/(BMASS+DMASS(I)+AMASS(I))
      IF (VELOSQ.LE.0.0)GO TO 1000
      V(I+1)=SQRT(VELOSQ)
C
C
C     SECTION TO COMPUTE THE WORK DONE BY DRAG
C     APPROXIMATE AVERAGE VELOCITY OVER A SECTION BY NEGLECTING THE DRAG
C     FIRST TIME OVER THE SECTION, AS DONE ABOVE
      VAVG=(V(I)+V(I+1))/2.
      IF(I.EQ.1) VAVG=(VO+V(I+1))/2.
      WDRAG=.5*BWD*CD*AREA(I)*DX*VAVG**2
C
      VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I)-WDRAG)/(BMASS+DMASS(I)+AMAS
     2S(I))
      IF (VELOSQ.LE.0.0)GO TO 1000
```

```
      V(I+1)=SQRT(VELOSQ)
C
C     CALCULATE E AT NEXT SECTION
      E(I+1)=BMASS*V(I+1)**2/2.
C
C     CALCULATE ENERGY DISSIPATED BY ADDED MASS EFFECTS, EAM
      EAM=.5*(AMASS(I)*V(I+1)**2-2.0*AMASS1+DMASS(I)*V(I+1)**2)
C
C     COMPUTE PENETRATION DEPTH
      XXX=I*DX
C
C     PRINT THE SECTION, DEPTH OF PENETRATION, VELOCITY AT THE END OF
C     SECTION, SHEAR STRENGTH IN SECTION, BODY ENERGY AT END OF SECTION,
C     WORKDONE BY   SEDIMENT, ADDED MASS PLUS DISPLACED MASS, BUOYANCY,
C     AND DRAG
C
      WRITE(6,2600) I,XXX,V(I+1),SPS,E(I+1),WS(I),EAM,WB(I),WDRAG
 2000 CONTINUE
 1000 CONTINUE
 2050 FORMAT(I5)
 2060 FORMAT(' ',I3)
 2100 FORMAT(F5.1,12F5.2)
 2200 FORMAT('1',40X,'CONE '//9X,'RADIUS = ',F7.3,' FEET'/9X,'LENGTH = '
     2,F7.3,' FEET'/9X,'WEIGHT = ',F7.1,' LBS'/9X,'BULK WET DENSITY = '
     3,F6.3,' SLUGS PER CUBIC FOOT'/9X,'DRAG COEFFICIENT = ',F7.2///)
 2300 FORMAT(' ',10X,'IMPACT VELOCITY EQUALS',F5.1///10X,'SEDIMENT SHEAR
     2 STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE'//15X,12F6.2//)
 2500 FORMAT('0',18X,'CONDITIONS AT THE END OF SECTION',19X,'WORK DONE I
     2N SECTION - FOOT POUNDS'///16X,'ITERATION',1X,'PENETRATION',2X,'VE
     3LOCITY',3X,'SHEAR',5X,'BODY ENERGY',6X,'STATIC',4X,'SEDIMENT',4X,'
     4BUOY WT',3X,'FORM DRAG'/17X,'SECTION',6X,'FEET',8X,'FT/SEC',2X,'ST
     5RENGTH PSF',4X,'FT-LBS',7X,'FORCES',4X,'INERTIA',6X,'FORCES',4X,'F
     6ORCES'//)
 2600 FORMAT(' ',16X,I3,3X,F12.2,7F12.3)
      STOP
      END
```

```
                                                              CONE
RADIUS =     1.474 FEET
LENGTH =     5.500 FEET
WEIGHT =  1127.0 LBS
BULK WET DENSITY =    2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  0.30

 IMPACT VELOCITY EQUALS  0.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

     0.48  0.69  1.10  1.38  1.86  2.50  2.31  2.52  2.81  2.65  2.50  2.80

                 CONDITIONS AT THE END OF SECTION
                                                                  WORK DONE IN SECTION - FOOT POUNDS

 ITERATION PENETRATION   VELOCITY     SHEAR     BODY ENERGY     STATIC      SEDIMENT     BUOYANT     FORM DRAG
  SECTION      FEET       FT/SEC   STRENGTH-PSF    FT-LBS       FORCES      INERTIA      FORCES       FORCES

     1         0.05    [illegible] [illegible]      56.350      0.000        0.000        0.000        0.000
     2         0.10    [illegible] [illegible]     112.697      0.002        0.001        0.000        0.000
     3         0.15    [illegible] [illegible]     168.035      0.007        0.004        0.001        0.001
     4         0.20    [illegible] [illegible]     225.352      0.020        0.010        0.002        0.002
     5         0.25    [illegible] [illegible]     281.632      0.047        0.020        0.004        0.003
     6         0.30    [illegible] [illegible]     337.855      0.074        0.036        0.007        0.006
     7         0.35    [illegible] [illegible]     393.998      0.126    [illegible]      0.011        0.010
     8         0.40    [illegible] [illegible]     450.032   [illegible] [illegible]      0.017        0.016
     9         0.45    [illegible] [illegible]     505.925   [illegible] [illegible]      0.025        0.023
    10         0.50    [illegible] [illegible]     561.637   [illegible]     0.177        0.035        0.032
    11         0.55    [illegible] [illegible]     617.128      0.530        0.237        0.048        0.043
    12         0.60    [illegible] [illegible]     672.353      0.697    [illegible]      0.063        0.056
    13         0.65    [illegible] [illegible]     727.260      0.895    [illegible]      0.080        0.072
    14         0.70    [illegible] [illegible]     781.797      1.127    [illegible]      0.101        0.090
    15         0.75    [illegible] [illegible]     835.904      1.397    [illegible]      0.126        0.112
    16         0.80    [illegible] [illegible]     889.520      1.706        0.733        0.153        0.136
    17         0.85    [illegible] [illegible]     942.578      2.058    [illegible]      0.185        0.164
    18         0.90    [illegible] [illegible]     995.009      2.455    [illegible]      0.221        0.195
    19         0.95    [illegible] [illegible]    1046.740      2.901        1.223        0.261        0.229
    20         1.00    [illegible] [illegible]    1097.693      3.397        1.427        0.305    [illegible]
    21         1.05    [illegible] [illegible]    1147.842      3.893        1.644        0.354        0.310
    22         1.10    [illegible] [illegible]    1197.172      4.374        1.891        0.409        0.356
    23         1.15    [illegible] [illegible]    1245.520      4.892        2.136        0.468        0.406
    24         1.20    [illegible] [illegible]    1293.118      5.447        2.410        0.534        0.460
    25         1.25    [illegible] [illegible]    1339.600      6.041        2.703        0.605        0.519
    26         1.30    [illegible] [illegible]    1384.996      6.675        3.015        0.682        0.581
    27         1.35    [illegible] [illegible]    1429.237      7.349        3.346        0.765    [illegible]
    28         1.40    [illegible] [illegible]    1472.253      8.066        3.694        0.855        0.720
    29         1.45    [illegible] [illegible]    1513.970      8.826        4.058        0.952        0.796
    30         1.50    [illegible] [illegible]    1554.018      9.630        4.439        1.055        0.876
    31         1.55    [illegible] [illegible]    1593.225     10.481        4.835        1.166        0.961
    32         1.60    [illegible] [illegible]    1630.616     11.378        5.245        1.295        1.050
    33         1.65       9.754    [illegible]    1666.421     12.324        5.657        1.411        1.143
```

34	1.70	9.854	89.532	1700.565	13.319	6.100	1.545	1.240
35	1.75	9.947	91.044	[illegible]	14.365	6.542	1.588	1.341
36	1.80	[illegible]	[illegible]	[illegible]	15.462	6.990	[illegible]	1.445
37	1.85	10.116	[illegible]	[illegible]	16.512	7.443	1.999	1.555
38	1.90	[illegible]	[illegible]	[illegible]	17.917	7.898	2.167	1.667
39	1.95	[illegible]	[illegible]	[illegible]	19.077	8.353	2.345	1.782
40	2.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.900
41	2.05	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.730	2.021
42	2.10	[illegible]	[illegible]	[illegible]	[illegible]	9.672	2.937	2.144
43	2.15	[illegible]	[illegible]	[illegible]	[illegible]	10.046	3.155	2.263
44	2.20	[illegible]	[illegible]	[illegible]	[illegible]	10.415	[illegible]	2.394
45	2.25	[illegible]	[illegible]	[illegible]	[illegible]	10.716	[illegible]	2.520
46	2.30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.645
47	2.35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.771
48	2.40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.404	2.896
49	2.45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.018
50	2.50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.139
51	2.55	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.256
52	2.60	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.369
53	2.65	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.478
54	2.70	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.581
55	2.75	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
56	2.80	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.762
57	2.85	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.842
58	2.90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.922
59	2.95	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.985
60	3.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.035
61	3.05	[illegible]	[illegible]	[illegible]	[illegible]	7.701	[illegible]	4.077
62	3.10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.105
63	3.15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.120
64	3.20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.121
65	3.25	[illegible]	[illegible]	[illegible]	[illegible]	3.077	[illegible]	[illegible]
66	3.30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.080
67	3.35	[illegible]	[illegible]	[illegible]	[illegible]	-0.060	[illegible]	4.035
68	3.40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12.637	3.972
69	3.45	[illegible]	[illegible]	[illegible]	[illegible]	-3.901	[illegible]	3.891
70	3.50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.791
71	3.55	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.671
72	3.60	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15.019	3.530
73	3.65	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15.658	3.367
74	3.70	[illegible]	[illegible]	[illegible]	[illegible]	-16.029	16.315	3.181
75	3.75	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	16.990	2.971
76	3.80	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17.683	2.737
77	3.85	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18.395	2.477
78	3.90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	19.126	2.191
79	3.95	[illegible]	[illegible]	[illegible]	[illegible]	-32.753	19.875	1.877
80	4.00	[illegible]	[illegible]	[illegible]	165.641	-36.672	20.645	1.535
81	4.05	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	21.434	1.161
82	4.10	[illegible]	[illegible]	[illegible]	[illegible]	-45.737	22.242	0.752
83	4.15	[illegible]	[illegible]	[illegible]	[illegible]	-50.731	23.071	0.284

```
RADIUS =    1.474 FEET
LENGTH =    5.500 FEET
WEIGHT =  1127.0 LBS
BULK WET DENSITY =    2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  0.30


 IMPACT VELOCITY EQUALS  5.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
      0.65  0.63  0.68  1.80  2.32  2.56  2.51  2.26  1.89  1.64  1.60  1.79

                 CONDITIONS AT THE END OF SECTION                    WORK DONE IN SECTION - FOOT POUNDS

    ITERATION PENETRATION    VELOCITY   SHEAR    BODY ENERGY     STATIC     SEDIMENT     BUOYANT    FORM DRAG
     SECTION      FEET        FT/SEC  STRENGTH PSF  FT-LBS       FORCES     INERTIA      FORCES     FORCES

        1          0.05        5.312     2.340     494.222       0.000       0.000       0.000       0.000
        2          0.10        5.607     7.020     550.565       0.002       0.003       0.000       0.001
        3          0.15        5.886    11.700     600.891       0.010       0.011       0.001       0.002
        4          0.20        6.153    16.380     661.181       0.027       0.023       0.002       0.005
        5          0.25        6.409    21.060     719.424       0.057       0.042       0.004       0.009
        6          0.30        6.654    25.740     777.575       0.103       0.069       0.007       0.015
        7          0.35        6.891    30.420     831.615       0.170       0.105       0.011       0.022
        8          0.40        7.118    35.100     887.503       0.262       0.151       0.017       0.032
        9          0.45        7.338    39.780     943.194   [illegible]     0.208       0.025       0.043
       10          0.50        7.551    44.460     995.641       0.532       0.278       0.035       0.057
       11          0.55        7.757    49.140    1057.790       0.718       0.360       0.048       0.074
       12          0.60        7.956    53.820    1109.587       0.942       0.457       0.063       0.094
       13          0.65        8.149    58.500    1162.955   [illegible]     0.569       0.080       0.116
       14          0.70        8.335    63.180    1216.837   [illegible]     0.697       0.101       0.142
       15          0.75        8.516    67.860    1270.157   [illegible]     0.841       0.126       0.172
       16          0.80        8.691    72.540    1322.835   [illegible]     1.003       0.153       0.204
       17          0.85        8.860    77.220    1374.789   [illegible]     1.183       0.185       0.241
       18          0.90        9.023    81.900    1425.939   [illegible]     1.382       0.221       0.281
       19          0.95        9.180    86.580    1476.167   [illegible]     1.599       0.261       0.326
       20          1.00        9.332    91.260    1525.402   [illegible]     1.835       0.305       0.374
       21          1.05        9.479    93.528    1572.669       5.410       2.091       0.354       0.427
       22          1.10        9.620    93.384    1621.034       5.722       2.369       0.409       0.485
       23          1.15        9.757    93.240    1667.446       6.257       2.667       0.468       0.546
       24          1.20        9.889    93.096    1712.850       6.815       2.985       0.534       0.613
       25          1.25       10.016    92.952    1757.193   [illegible]     3.323       0.605       0.683
       26          1.30       10.139    92.808    1803.421   [illegible]     3.681       0.682       0.759
       27          1.35       10.256    92.664    1842.480       8.635       4.060       0.765       0.839
       28          1.40       10.369    92.520    1883.320       9.275       4.457       0.855       0.925
       29          1.45       10.478    92.376    1922.884       9.946       4.873       0.952       1.015
       30          1.50       10.582    92.232    1961.123      10.640       5.307       1.055       1.109
       31          1.55       10.680    92.088    1997.983      11.355       5.758       1.166       1.209
       32          1.60       10.775    91.944    2033.417      12.083       6.225       1.285       1.313
       33          1.65       10.864    91.800    2067.373   [illegible]     6.707       1.411       1.422
```

34	1.70	10.949	91.656	[illegible]	13.635	7.203	1.545	1.535
35	1.75	[illegible]	[illegible]	[illegible]	14.438	7.711	1.688	1.653
36	1.80	11.105	[illegible]	[illegible]	15.263	8.229	1.839	1.775
37	1.85	[illegible]	[illegible]	2187.486	16.110	8.757	[illegible]	1.901
38	1.90	[illegible]	[illegible]	[illegible]	16.978	[illegible]	2.167	2.031
39	1.95	[illegible]	[illegible]	[illegible]	17.867	[illegible]	[illegible]	2.165
40	2.00	[illegible]	[illegible]	[illegible]	18.779	10.375	[illegible]	2.303
41	2.05	[illegible]	[illegible]	[illegible]	19.764	10.916	[illegible]	2.445
42	2.10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
43	2.15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.736
44	2.20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
45	2.25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
46	2.30	[illegible]	[illegible]	[illegible]	[illegible]	13.502	[illegible]	[illegible]
47	2.35	[illegible]	[illegible]	[illegible]	[illegible]	13.979	[illegible]	3.346
48	2.40	[illegible]	[illegible]	[illegible]	27.940	14.434	[illegible]	3.502
49	2.45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
50	2.50	[illegible]	[illegible]	[illegible]	30.576	[illegible]	[illegible]	[illegible]
51	2.55	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.973
52	2.60	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
53	2.65	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
54	2.70	[illegible]	[illegible]	[illegible]	36.264	[illegible]	[illegible]	[illegible]
55	2.75	[illegible]	[illegible]	[illegible]	37.774	[illegible]	[illegible]	[illegible]
56	2.80	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
57	2.85	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
58	2.90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
59	2.95	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
60	3.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
61	3.05	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
62	3.10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
63	3.15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
64	3.20	[illegible]	[illegible]	[illegible]	67.424	[illegible]	[illegible]	[illegible]
65	3.25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
66	3.30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11.546	[illegible]
67	3.35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12.083	[illegible]
68	3.40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
69	3.45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
70	3.50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
71	3.55	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
72	3.60	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15.019	5.545
73	3.65	[illegible]	[illegible]	[illegible]	[illegible]	-10.491	15.658	[illegible]
74	3.70	[illegible]	[illegible]	[illegible]	[illegible]	-14.669	16.315	5.201
75	3.75	[illegible]	[illegible]	[illegible]	158.069	-19.205	16.990	4.974
76	3.80	[illegible]	[illegible]	[illegible]	[illegible]	-24.109	[illegible]	4.705
77	3.85	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
78	3.90	[illegible]	[illegible]	[illegible]	[illegible]	-35.071	19.126	4.040
79	3.95	[illegible]	[illegible]	[illegible]	[illegible]	-41.153	[illegible]	3.638
80	4.00	[illegible]	[illegible]	[illegible]	[illegible]	-47.650	20.645	3.187
81	4.05	[illegible]	[illegible]	[illegible]	224.260	[illegible]	[illegible]	[illegible]
82	4.10	[illegible]	[illegible]	[illegible]	[illegible]	-60.036	22.242	2.142
83	4.15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	23.071	1.552
84	4.20	[illegible]	[illegible]	[illegible]	[illegible]	-73.047	[illegible]	0.908

```
                                          CONE
RADIUS =    1.474 FEET
LENGTH =    5.500 FEET
WEIGHT =  11[illegible]7.0 LBS
BULK WET DENSITY =   2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  0.30


 IMPACT VELOCITY EQUALS 10.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
     0.30  0.23  0.47  2.05  [illegible]  3.21  [illegible]  [illegible]  [illegible]  3.35  2.22  3.12


              CONDITIONS AT THE END OF SECTION                          WORK DONE IN SECTION - FOOT POUNDS

ITERATION PENETRATION    VELOCITY   [illegible]   BODY ENERGY      STATIC     SEDIMENT      [illegible]    FORM DRAG
 SECTION      FEET        [illegible]              [illegible]      FORCES     INERTIA       [illegible]    FORCES

   1          0.05        10.160      [illegible]   18[illegible].843   0.000   [illegible]     0.000       0.000
   2          0.10        10.317      [illegible]   18[illegible].178   0.001   [illegible]     0.000       0.003
   3          0.15        10.473      [illegible]   19[illegible].484   0.004   [illegible]     0.001       0.008
   4          0.20        10.624      [illegible]   19[illegible].740   0.012   [illegible]     0.002       0.016
   5          0.25        10.775      [illegible]   20[illegible].[illegible]22   0.026   [illegible]     0.004       0.027
   6          0.30        10.92[illegible]   1[illegible].[illegible]   20[illegible].006   0.048   [illegible]     0.007       0.041
   7          0.35        11.06[illegible]   1[illegible].0[illegible]   21[illegible].959   0.079   [illegible]     0.011       0.059
   8          0.40        11.20[illegible]   1[illegible].2[illegible]   22[illegible].748   0.121   [illegible]     0.017       0.080
   9          0.45        11.354      1[illegible].3[illegible]   22[illegible].338   0.176   [illegible]     0.025       0.106
  10          0.50        11.488      2[illegible].5[illegible]   23[illegible].689   0.245   [illegible]     0.035       0.135
  11          0.55        11.624      2[illegible].6[illegible]   23[illegible].758   0.331   0.7[illegible]1     0.048       0.169
  12          0.60        11.759      2[illegible].8[illegible]   24[illegible].498   0.435   0.[illegible]3     0.063       0.208
  13          0.65        11.889      27.0[illegible]   24[illegible].250   0.559   1.[illegible]6     0.080       0.251
  14          0.70        12.019      2[illegible].1[illegible]   25[illegible].791   0.704   1.[illegible]12     0.101       0.299
  15          0.75        12.14[illegible]   3[illegible].3[illegible]   25[illegible].234   0.873   1.[illegible]     0.126       0.353
  16          0.80        12.269      3[illegible]   26[illegible].135   1.066   1.[illegible]17     0.153       0.411
  17          0.85        12.389      3[illegible]   26[illegible].830   1.286   2.[illegible]     0.185       0.476
  18          0.90        12.508      3[illegible]   27[illegible].055   1.535   2.[illegible]22     0.221       0.545
  19          0.95        12.623      3[illegible].9[illegible]   27[illegible].943   1.813   2.7[illegible]4     0.261       0.621
  20          1.00        12.736      4[illegible].12[illegible]   28[illegible].029   2.123   3.[illegible]3     0.305       0.703
  21          1.05        12.846      4[illegible].94[illegible]   28[illegible].313   2.392   3.[illegible]20     0.354       0.790
  22          1.10        12.953      4[illegible].44[illegible]   29[illegible].316   2.601   3.[illegible]3     0.409       0.884
  23          1.15        13.058      4[illegible].94[illegible]   29[illegible].[illegible]92   2.814   4.4[illegible]6     0.458       0.984
  24          1.20        13.160      4[illegible].4[illegible]   303[illegible].[illegible]95   3.033   4.[illegible]7     0.534       1.091
  25          1.25        13.259      40.9[illegible]   307[illegible].[illegible]82   3.257   5.3[illegible]6     0.605       1.204
  26          1.30        13.355      40.42[illegible]   312[illegible].[illegible]07   3.485   5.[illegible]4     0.682       1.324
  27          1.35        13.449      39.92[illegible]   316[illegible].[illegible]25   3.716   6.4[illegible]0     0.765       1.450
  28          1.40        13.540      39.42[illegible]   321[illegible].[illegible]93   3.952   7.0[illegible]3     0.855       1.583
  29          1.45        13.627      38.91[illegible]   325[illegible].[illegible]62   4.190   7.715     0.952       1.723
  30          1.50        13.712      38.41[illegible]   329[illegible].[illegible]91   4.431   8.364     1.055       1.870
  31          1.55        13.794      37.90[illegible]   333[illegible].[illegible]38   4.674   9.039     1.156       2.023
  32          1.60        13.871      37.40[illegible]   337[illegible].[illegible]57   4.920   9.741     1.265       2.183
  33          1.65        13.94[illegible]   36.90[illegible]   340[illegible].[illegible]12   5.166  10.4[illegible]7     1.411       2.350
  34          1.70        14.022      36.39[illegible]   344[illegible].[illegible]59   5.414  11.21[illegible]     1.545       2.524
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35	1.75	14.091	35.892	3477.859	5.663	11.992	1.688	2.704
36	1.80	14.158	[illegible]	3510.777	5.912	12.789	1.839	2.891
37	1.85	14.221	[illegible]	3542.277	6.160	13.605	1.999	3.084
38	1.90	14.281	[illegible]	3572.324	6.409	14.442	2.167	3.284
39	1.95	14.338	[illegible]	[illegible]	6.656	15.296	2.345	3.490
40	2.00	14.392	[illegible]	[illegible]	6.902	16.167	2.533	3.702
41	2.05	14.442	[illegible]	[illegible]	7.389	17.038	2.730	3.920
42	2.10	14.488	[illegible]	[illegible]	8.153	17.901	2.937	4.144
43	2.15	14.529	[illegible]	[illegible]	8.964	18.765	3.155	4.372
44	2.20	14.567	[illegible]	[illegible]	9.825	19.627	3.383	4.605
45	2.25	14.599	[illegible]	[illegible]	10.735	20.484	3.621	4.843
46	2.30	14.627	[illegible]	[illegible]	11.697	21.330	3.871	5.084
47	2.35	14.651	[illegible]	[illegible]	12.712	22.162	4.132	5.329
48	2.40	14.669	[illegible]	[illegible]	13.782	22.977	4.404	5.577
49	2.45	14.683	[illegible]	[illegible]	14.907	23.771	[illegible]	5.827
50	2.50	[illegible]	[illegible]	8107.480	41.778	46.177	4.984	13.085
51	2.55	[illegible]	[illegible]	8053.281	44.627	47.081	5.292	[illegible]
52	2.60	[illegible]	[illegible]	7994.531	47.602	47.885	5.613	13.975
53	2.65	[illegible]	[illegible]	7931.211	50.705	48.586	5.946	14.413
54	2.70	[illegible]	[illegible]	7363.293	53.938	49.170	6.292	14.844
55	2.75	[illegible]	[illegible]	7790.762	57.306	49.631	6.652	15.268
56	2.80	[illegible]	[illegible]	7713.613	60.810	49.962	7.025	[illegible]
57	2.85	[illegible]	[illegible]	7631.840	64.453	50.151	7.411	16.086
58	2.90	20.756	[illegible]	7545.449	68.238	50.191	7.812	[illegible]
59	2.95	20.630	159.084	7454.461	72.167	50.074	8.226	[illegible]
60	3.00	20.498	162.468	7358.879	[illegible]	49.788	8.655	17.223
61	3.05	20.357	167.724	7257.984	[illegible]	49.175	9.099	17.571
62	3.10	20.206	174.852	7151.016	[illegible]	48.185	9.558	[illegible]
63	3.15	20.046	181.980	7037.034	94.229	[illegible]	10.032	[illegible]
64	3.20	19.875	189.108	6918.750	101.078	[illegible]	10.521	[illegible]
65	3.25	19.694	196.236	6793.465	[illegible]	[illegible]	11.026	[illegible]
66	3.30	19.503	203.364	6662.078	[illegible]	[illegible]	11.546	18.961
67	3.35	19.301	210.492	6524.609	[illegible]	[illegible]	12.083	19.154
68	3.40	19.087	217.620	6381.078	[illegible]	[illegible]	12.637	19.314
69	3.45	18.862	224.748	6231.520	[illegible]	[illegible]	13.207	[illegible]
70	3.50	18.625	231.876	[illegible]	[illegible]	[illegible]	13.793	19.527
71	3.55	18.376	239.004	[illegible]	[illegible]	[illegible]	14.397	19.576
72	3.60	18.114	246.132	[illegible]	[illegible]	[illegible]	15.019	[illegible]
73	3.65	17.839	253.260	[illegible]	[illegible]	[illegible]	15.658	[illegible]
74	3.70	17.551	260.388	[illegible]	[illegible]	13.001	16.315	[illegible]
75	3.75	17.248	267.516	[illegible]	[illegible]	7.767	16.990	19.337
76	3.80	16.930	274.644	[illegible]	[illegible]	2.130	17.683	[illegible]
77	3.85	16.597	281.772	[illegible]	[illegible]	-3.918	18.395	[illegible]
78	3.90	16.247	[illegible]	[illegible]	[illegible]	-10.391	19.126	18.642
79	3.95	15.881	[illegible]	[illegible]	[illegible]	-17.297	19.875	18.302
80	4.00	15.496	[illegible]	[illegible]	[illegible]	-24.643	20.645	17.904
81	4.05	15.095	307.476	[illegible]	264.121	-31.662	21.434	17.449
82	4.10	14.679	[illegible]	[illegible]	[illegible]	[illegible]	22.242	16.943
83	4.15	14.248	[illegible]	[illegible]	[illegible]	[illegible]	23.071	[illegible]
84	4.20	13.801	[illegible]	[illegible]	[illegible]	[illegible]	23.920	[illegible]
85	4.25	13.337	[illegible]	[illegible]	[illegible]	[illegible]	24.790	15.133
86	4.30	12.853	[illegible]	[illegible]	[illegible]	[illegible]	25.680	14.430
87	4.35	12.348	[illegible]	[illegible]	[illegible]	[illegible]	26.592	13.675
88	4.40	11.820	[illegible]	[illegible]	[illegible]	-83.196	27.525	12.870

88	4.45	11.265	319.572	2202.729	331.785	-91.605	28.479	12.012
90	4.50	10.630	321.024	1987.557	340.930	-100.269	29.456	11.102
91	4.55	10.060	322.506	1772.165	350.233	-109.186	30.454	10.139
92	4.60	9.518	324.108	1556.978	359.694	-118.356	31.475	9.123
93	4.65	8.995	325.640	1341.215	369.314	-127.773	32.518	8.053
[illegible]	4.70	7.978	327.172	1095.291	379.094	-137.434	33.584	6.926
95	4.75	7.036	328.644	889.521	389.037	-147.339	34.673	5.742
[illegible]	4.80	6.004	330.136	644.013	399.142	-157.472	35.785	4.512
97	4.85	4.909	331.648	428.674	409.411	-167.860	36.921	3.216
98	4.90	3.376	333.110	193.314	419.945	-178.464	38.081	1.847

89	4.45	11.265	319.572	2222.729	331.785	-91.605	28.479	12.012
90	4.50	10.[illegible]	321.0[illegible]	1997.957	340.930	-100.260	29.456	11.102
91	4.55	10.[illegible]	322.5[illegible]	1772.565	350.233	-109.126	30.454	10.139
92	4.60	9.[illegible]	324.[illegible]	1546.978	359.694	-118.356	31.475	9.123
93	4.65	8.[illegible]	325.[illegible]	1321.215	369.314	-127.772	32.518	8.053
94	4.70	7.[illegible]	327.[illegible]	1095.391	379.094	-137.434	33.584	6.928
95	4.75	7.[illegible]	328.[illegible]	869.621	389.037	-147.330	34.673	5.748
96	4.80	6.[illegible]	330.1[illegible]	644.013	399.142	-157.482	35.785	4.512
97	4.85	4.[illegible]	331.[illegible]	418.574	409.411	-167.860	36.921	3.216
98	4.90	3.[illegible]	333.[illegible]	193.714	419.846	-178.464	38.081	1.847

```
                                                CONE
RADIUS =     1.474 FEET
LENGTH =     5.500 FEET
WEIGHT =   1127.0 LBS
BULK WET DENSITY =    2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  0.30

 IMPACT VELOCITY EQUALS 15.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
     0.30  0.23  0.28  0.76  1.77  1.67  2.11  2.90  3.40  3.89  3.84  3.89

            CONDITIONS AT THE END OF SECTION
                                                            WORK DONE IN SECTION - FOOT POUNDS
ITERATION PENETRATION   VELOCITY   SHEAR      BODY ENERGY     STATIC     SEDIMENT     BUOYANT    FORM DRAG
 SECTION      FEET       FT/SEC  STRENGTH PSF   FT-LBS        FORCES     INERTIA      FORCES     FORCES

    1         0.05       15.107      1.080    399[illegible].[illegible]  0.000   0.00[illegible]   0.000    0.001
    2         0.10       15.21[illegible]  3.240    405[illegible].[illegible]  0.001   0.0[illegible]   0.000    0.00[illegible]
    3         0.15       15.31[illegible]  5.400    410[illegible].[illegible]  0.004   0.0[illegible]   0.001    0.01[illegible]
    4         0.20       15.42[illegible]  7.560    416[illegible].[illegible]  0.012   0.1[illegible]   0.002    0.03[illegible]
    5         0.25       15.52[illegible]  9.720    422[illegible].[illegible]  0.026   0.2[illegible]   0.004    0.05[illegible]
    6         0.30       15.62[illegible] 11.880    427[illegible].[illegible]  0.048   0.3[illegible]   0.007    0.08[illegible]
    7         0.35       15.72[illegible] 14.040    433[illegible].[illegible]  0.079   0.4[illegible]   0.011    0.11[illegible]
    8         0.40       15.83[illegible] 16.200    438[illegible].[illegible]  0.121   0.6[illegible]   0.017    0.16[illegible]
    9         0.45       15.92[illegible] 18.360    444[illegible].[illegible]  0.176   0.8[illegible]   0.025    0.20[illegible]
   10         0.50       16.02[illegible] 20.520    449[illegible].[illegible]  0.245   1.0[illegible]   0.035    0.26[illegible]
   11         0.55       16.12[illegible] 22.680    455[illegible].[illegible]  0.331   1.34[illegible]  0.048    0.327
   12         0.60       16.218     24.840    460[illegible].[illegible]  0.435   1.64[illegible]  0.063    0.397
   13         0.65       16.311     27.000    465[illegible].[illegible]  0.559   1.9[illegible]   0.080    0.475
   14         0.70       16.403     29.160    4712.[illegible]   0.704   2.3[illegible]   0.101    0.560
   15         0.75       16.493     31.320    4764.[illegible]   0.873   2.7[illegible]   0.126    0.654
   16         0.80       16.582     33.480    4815.[illegible]   1.066   3.1[illegible]   0.153    0.755
   17         0.85       16.668     35.640    4866.[illegible]   1.286   3.6[illegible]7  0.185    0.865
   18         0.90       16.753     37.800    4915.[illegible]   1.535   4.1[illegible]   0.221    0.983
   19         0.95       16.835     39.960    4964.[illegible]   1.813   4.6[illegible]9  0.261    1.109
   20         1.00       16.915     42.120    5011.[illegible]   2.123   5.245    0.305    1.245
   21         1.05       16.993     42.948    5057.[illegible]   2.392   5.858    0.354    1.389
   22         1.10       17.069     42.444    5103.[illegible]   2.601   6.509    0.409    1.541
   23         1.15       17.143     41.940    5147.[illegible]   2.814   7.19[illegible]  0.468    1.703
   24         1.20       17.214     41.436    5190.[illegible]   3.033   7.921    0.534    1.873
   25         1.25       17.283     40.932    5231.[illegible]   3.257   8.68[illegible]  0.605    2.053
   26         1.30       17.350     40.428    5272.[illegible]   3.485   9.47[illegible]  0.682    2.241
   27         1.35       17.414     39.924    5311.[illegible]   3.716  10.31[illegible]  0.765    2.439
   28         1.40       17.476     39.420    5349.[illegible]   3.952  11.18[illegible]  0.855    2.646
   29         1.45       17.535     38.916    5385.[illegible]   4.190  12.08[illegible]  0.952    2.861
   30         1.50       17.591     38.412    5420.[illegible]   4.431  13.019    1.055    3.086
   31         1.55       17.645     37.908    5453.[illegible]   4.674  13.987    1.166    3.320
   32         1.60       17.696     37.404    5494.[illegible]   4.920  14.986    1.2[illegible]5  3.562
   33         1.65       17.744     36.900    5514.[illegible]   5.166  16.014    1.411    3.813
   34         1.70       17.790     36.396    5543.[illegible]   5.414  17.071    1.545    4.073
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35	1.75	17.832	35.892	5569.578	5.663	18.154	1.688	4.341
36	1.80	17.872	35.328	5594.273	5.912	19.262	1.839	4.618
37	1.85	17.908	34.884	5617.152	6.160	20.393	1.990	4.903
38	1.90	17.942	34.359	5639.168	6.409	21.544	2.167	5.195
39	1.95	17.972	33.876	5657.293	6.656	22.715	2.345	5.496
40	2.00	17.999	33.372	5674.484	6.902	23.901	2.533	5.804
41	2.05	18.023	[illegible]	5689.629	7.240	25.096	2.730	6.119
42	2.10	18.044	[illegible]	5702.605	7.684	26.295	2.937	6.441
43	2.15	18.061	[illegible]	5713.371	8.145	27.499	3.155	6.769
44	2.20	18.074	[illegible]	[illegible]	8.624	28.705	3.383	7.103
45	2.25	18.084	[illegible]	[illegible]	9.119	29.910	3.621	7.444
46	2.30	[illegible]	[illegible]	[illegible]	9.632	31.110	3.871	7.789
47	2.35	[illegible]	[illegible]	[illegible]	10.164	32.302	4.132	8.139
48	2.40	[illegible]	[illegible]	[illegible]	10.713	33.482	4.404	8.494
49	2.45	[illegible]	[illegible]	[illegible]	[illegible]	34.647	4.688	8.852
50	2.50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.984	6.080
51	2.55	[illegible]	[illegible]	[illegible]	[illegible]	25.274	5.292	6.333
52	2.60	[illegible]	[illegible]	[illegible]	18.641	25.975	5.613	6.588
53	2.65	14.670	[illegible]	[illegible]	[illegible]	26.637	5.946	6.844
54	2.70	[illegible]	[illegible]	[illegible]	21.417	[illegible]	6.292	7.099
55	2.75	[illegible]	[illegible]	[illegible]	[illegible]	27.820	6.652	7.353
56	2.80	[illegible]	[illegible]	3734.246	[illegible]	[illegible]	7.025	7.606
57	2.85	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.411	7.857
58	2.90	[illegible]	[illegible]	[illegible]	[illegible]	29.174	7.812	8.104
59	2.95	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.226	8.349
60	3.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.655	8.537
61	3.05	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.822
62	3.10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9.041
63	3.15	[illegible]	[illegible]	[illegible]	49.771	27.615	10.032	[illegible]
64	3.20	[illegible]	[illegible]	[illegible]	57.457	[illegible]	10.521	[illegible]
65	3.25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11.026	[illegible]
66	3.30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
67	3.35	[illegible]	[illegible]	[illegible]	[illegible]	20.499	[illegible]	[illegible]
68	3.40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12.637	[illegible]
69	3.45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13.207	[illegible]
70	3.50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
71	3.55	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
72	3.60	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
73	3.65	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
74	3.70	[illegible]	[illegible]	[illegible]	[illegible]	-5.651	[illegible]	9.637
75	3.75	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9.440
76	3.80	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9.194
77	3.85	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.893
78	3.90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.537
79	3.95	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.122
80	4.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20.645	7.646
81	4.05	[illegible]	[illegible]	[illegible]	255.061	[illegible]	21.434	7.109
82	4.10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	22.242	6.521
83	4.15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	23.071	5.884
84	4.20	[illegible]	[illegible]	[illegible]	[illegible]	-74.526	23.920	5.197
85	4.25	7.003	[illegible]	[illegible]	294.123	[illegible]	24.790	4.459
86	4.30	[illegible]	[illegible]	[illegible]	304.474	[illegible]	25.680	3.669
87	4.35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	26.592	2.824
88	4.40	[illegible]	[illegible]	[illegible]	[illegible]	-107.257	27.525	1.920
89	4.45	[illegible]	[illegible]	97.777	335.930	-115.233	28.479	0.935

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IMPACT VELOCITY EQUALS 20.0                           CONE
SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE             RADIUS =      1.474 FEET
                                                                             LENGTH =      5.500 FEET
     0.54  0.67  1.14  2.13  2.34  2.65  2.47  2.34  2.69  2.86  2.92  3.19  WEIGHT =   1127.0 LBS
                                                                             BULK WET DENSITY =    2.72
                                                                             DRAG COEFFICIENT =  0.70

              CONDITIONS AT THE END OF SECTION                        WORK DONE IN SECTION - FOOT POUNDS

 ITERATION PENETRATION   VELOCITY    SHEAR     BODY ENERGY     STATIC     SEDIMENT     BUOYANT     FORM DRAG
  SECTION     FEET        FT/SEC  STRENGTH PSF   FT-LBS        FORCES      INERTIA     FORCES       FORCES

     1        0.05    [illegible]     1.944    [illegible]     0.000       0.004       0.000        0.001
     2        0.10    [illegible]     5.832    [illegible]     0.002    [illegible]    0.000        0.010
     3        0.15    [illegible]     9.720    [illegible]     0.008    [illegible]    0.001        0.029
     4        0.20    [illegible]    13.608    [illegible]     0.022    [illegible] [illegible]     0.058
     5        0.25    [illegible]    17.496    [illegible]     0.047    [illegible] [illegible]     0.096
     6        0.30    [illegible]    21.384    [illegible]     0.086    [illegible] [illegible]     0.145
     7        0.35    [illegible]    25.272    [illegible]     0.142    [illegible] [illegible]     0.204
     8        0.40    [illegible]    29.160    [illegible]     0.217    [illegible] [illegible]     0.274
     9        0.45    [illegible]    33.048    [illegible]     0.317    [illegible] [illegible]     0.355
    10        0.50    [illegible]    36.936    [illegible]     0.442    [illegible] [illegible]     0.446
    11        0.55    [illegible]    40.824    [illegible]     0.597    [illegible] [illegible]     0.549
    12        0.60    [illegible]    44.712    [illegible]     0.784    [illegible] [illegible]     0.663
    13        0.65    [illegible]    48.600    [illegible]     1.007    [illegible] [illegible]     0.789
    14        0.70    [illegible]    52.488    [illegible]     1.268    [illegible] [illegible]     0.926
    15        0.75    [illegible]    56.376    [illegible]     1.571    [illegible] [illegible]     1.075
    16        0.80    [illegible]    60.264    [illegible]     1.919    [illegible] [illegible]     1.236
    17        0.85    [illegible]    64.152    [illegible]     2.315    [illegible] [illegible]     1.409
    18        0.90    [illegible]    68.040    [illegible]     2.762    [illegible] [illegible]     1.594
    19        0.95    [illegible]    71.928    [illegible]     3.263    [illegible] [illegible]     1.792
    20        1.00    [illegible]    75.816    [illegible]     3.821    [illegible] [illegible]     2.001
    21        1.05    [illegible]    78.228    [illegible]     4.358    [illegible] [illegible]     2.223
    22        1.10    [illegible]    79.164    [illegible]     4.851    [illegible] [illegible]     2.458
    23        1.15    [illegible]    80.100    [illegible]     5.375    [illegible] [illegible]     2.704
    24        1.20    [illegible]    81.036    [illegible]     5.932    [illegible] [illegible]     2.963
    25        1.25    [illegible]    81.972    [illegible]     6.522    [illegible] [illegible]     3.234
    26        1.30    [illegible]    82.908    [illegible]     7.146    [illegible] [illegible]     3.516
    27        1.35    [illegible]    83.844    [illegible]     7.805    [illegible] [illegible]     3.811
    28        1.40    [illegible]    84.780    [illegible]     8.499    [illegible] [illegible]     4.118
    29        1.45    [illegible]    85.716    [illegible]     9.229    [illegible]    0.952        4.436
    30        1.50    [illegible]    86.652    [illegible]     9.996    [illegible]    1.055        4.766
    31        1.55    [illegible]    87.588    [illegible]    10.801    [illegible]    1.166        5.107
    32        1.60    [illegible]    88.524    [illegible]    11.643    [illegible] [illegible]     5.459
    33        1.65    [illegible]    89.460    [illegible]    12.526    [illegible]    1.411        5.821
    34        1.70    [illegible]    90.396    [illegible]    13.447    [illegible]    1.545        6.193
    35        1.75    [illegible]    91.332    [illegible]    14.410    [illegible]    1.606        6.576
    36        1.80    [illegible]    92.268    8424.422      15.414    [illegible]    1.839        6.968
    37        1.85    [illegible]    93.204    [illegible]    16.460    [illegible]    1.999        7.368
    38        1.90    [illegible]    94.140    8424.004      17.548    [illegible]    2.167        7.777
    39        1.95    [illegible]    95.076    8419.020      18.681    [illegible]    2.345        8.195
    40        2.00    [illegible]    96.012    [illegible]    19.857    [illegible]    2.533        8.619
    41        2.05    [illegible]    98.172    8398.969      21.345      35.016       2.730        9.051
    42        2.10    [illegible]   101.556    8383.254      23.185      36.432       2.927        9.458
    43        2.15    [illegible]   104.940    8363.551      25.126      37.822       3.155        9.920
    44        2.20    [illegible]   108.324    8339.777      27.171      39.178       3.333       10.376
    45        2.25    [illegible]   111.708    8311.952      29.323      40.463       3.621       10.375
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46	2.30	21.742	115.092	8279.688	31.584	41.758	3.871	11.276
47	2.35	21.694	118.476	8243.227	33.958	42.967	4.132	11.729
48	2.40	21.640	121.860	8202.414	36.446	44.113	4.404	12.182
49	2.45	21.581	[illegible]	[illegible]	39.052	45.184	4.683	12.634
50	2.50	[illegible]	[illegible]	[illegible]	11.868	35.794	4.934	[illegible]
51	2.55	[illegible]	[illegible]	[illegible]	12.474	36.917	[illegible]	[illegible]
52	2.60	[illegible]	[illegible]	[illegible]	13.160	38.014	5.613	[illegible]
53	2.65	[illegible]	[illegible]	[illegible]	13.745	39.090	5.946	[illegible]
54	2.70	[illegible]	[illegible]	[illegible]	14.410	[illegible]	6.272	10.314
55	2.75	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
56	2.80	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
57	2.85	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.411	11.411
58	2.90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.812	[illegible]
59	2.95	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.226	[illegible]
60	3.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
61	3.05	17.728	[illegible]	[illegible]	20.401	[illegible]	[illegible]	[illegible]
62	3.10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
63	3.15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
64	3.20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
65	3.25	17.459	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
66	3.30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	14.976
67	3.35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12.053	[illegible]
68	3.40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
69	3.45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
70	3.50	[illegible]	[illegible]	[illegible]	[illegible]	44.197	[illegible]	[illegible]
71	3.55	16.869	[illegible]	[illegible]	[illegible]	43.230	14.397	[illegible]
72	3.60	16.746	[illegible]	[illegible]	[illegible]	[illegible]	15.019	16.617
73	3.65	16.617	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
74	3.70	16.482	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
75	3.75	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17.202
76	3.80	16.190	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
77	3.85	16.033	[illegible]	[illegible]	75.515	[illegible]	[illegible]	[illegible]
78	3.90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
79	3.95	[illegible]	[illegible]	[illegible]	85.161	[illegible]	19.975	17.667
80	4.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
81	4.05	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17.741
82	4.10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
83	4.15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	22.971	[illegible]
84	4.20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
85	4.25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
86	4.30	[illegible]	[illegible]	[illegible]	144.807	-3.441	[illegible]	[illegible]
87	4.35	[illegible]	[illegible]	[illegible]	155.426	-9.766	[illegible]	17.012
88	4.40	[illegible]	[illegible]	[illegible]	166.421	-16.507	[illegible]	[illegible]
89	4.45	[illegible]	[illegible]	[illegible]	177.797	-23.669	[illegible]	16.390
90	4.50	13.012	[illegible]	[illegible]	189.559	-31.264	[illegible]	[illegible]
91	4.55	12.674	[illegible]	[illegible]	201.714	-39.297	[illegible]	[illegible]
92	4.60	12.316	[illegible]	[illegible]	214.266	-47.776	31.475	[illegible]
93	4.65	11.957	[illegible]	[illegible]	227.223	-56.708	32.518	14.485
94	4.70	11.534	[illegible]	[illegible]	240.589	-66.035	33.554	13.861
95	4.75	11.106	[illegible]	[illegible]	254.372	-75.953	34.473	13.174
96	4.80	10.648	[illegible]	[illegible]	268.575	-86.282	[illegible]	12.422
97	4.85	10.159	[illegible]	[illegible]	283.206	-97.080	[illegible]	11.604
98	4.90	[illegible]	[illegible]	[illegible]	298.270	-108.380	38.031	10.719
99	4.95	[illegible]	[illegible]	[illegible]	313.772	-120.162	39.265	9.763
100	5.00	[illegible]	[illegible]	[illegible]	329.719	-132.439	40.473	8.734
101	5.05	7.771	[illegible]	[illegible]	340.765	[illegible]	41.705	7.645
102	5.10	[illegible]	[illegible]	[illegible]	346.597	[illegible]	42.963	[illegible]
103	5.15	[illegible]	[illegible]	[illegible]	352.459	[illegible]	44.245	5.333
104	5.20	[illegible]	[illegible]	[illegible]	358.345	-166.422	45.553	4.121
105	5.25	[illegible]	[illegible]	[illegible]	364.262	-174.579	46.886	2.869
106	5.30	2.748	[illegible]	[illegible]	370.204	-182.721	48.245	1.560

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ACT

A rational method is presented to predict the penetration of free-falling objects into deep-sea sediments by combining proven empirical theories from the field of soil mechanics with known hydrodynamic phenomena. The impact velocity of the object and the shear strength profile and density of the sediment are assumed to be known. The penetration problem was solved through the use of a computer by equating the work done during penetration to the energy of the object falling through air and impacting onto a modeled deep-sea sediment. The objects were simple geometric shapes ranging in weight from 500 to more than 1,000 pounds. The impact velocities ranged from zero to twenty feet-per-second. The results are compared with full scale tests and recommendations are made to extend the method to a water-sediment interface. The method successfully predicts the penetration of objects into weak, saturated, sediments within the accuracy of the state-of-the-art techniques for measuring the sediment mechanical properties. The impact duration time was observed to be relatively constant and independent of object velocity, shape, and weight implying that it may be a unique property of the dynamic behavior of a sediment type.

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